Report No. FAA-RD-80-117

LEVEL

AD-A095462

Project Report
Discrete Address Beacon System

ATC-101

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Initial Design and Experimental Implementation of the Traffic Advisory Service of ATARS

F19628-80-C-0002
DOT-FA72 WAI-261

3 November 1980

Prepared for the Federal Aviation Administration by

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LEXINGTON, MASSACHUSETTS

Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151.

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207 650

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-80-117	AD-A095 462	

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code
Initial Design and Experimental Implementation of the Traffic Advisory Service of ATARS	5. Report Date: 3 November 1980 6. Performing Organization Code:
7. Author(s): Jeffrey L. Gertz	8. Performing Organization Report No: ATC-101
9. Performing Organization Name and Address: Massachusetts Institute of Technology Lincoln Laboratory P.O. Box 73 Lexington, MA 02173	10. Work Unit No. (TRAIS): Proj. No. 052-241-04 11. Contract or Grant No.: DOT-FA72-WAI-261
12. Sponsoring Agency Name and Address: Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, DC 20591	13. Type of Report and Period Covered: Project Report 14. Sponsoring Agency Code:

15. Supplementary Notes

The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology, with the support of the Department of the Air Force under Contract F19628-80-C-0002.

16. Abstract

The FAA Automatic Traffic Advisory and Resolution Service (ATARS) is a ground-based collision avoidance system which utilizes surveillance data from the Discrete Address Beacon System (DABS). It computes traffic advisories and collision warnings using a ground computer independent of the ATC computer system, and delivers these messages to aircraft via the DABS data link. ATARS provides both a traffic advisory and a resolution (collision avoidance) service to aircraft equipped with a DABS transponder, an altitude encoder (mode C), and an ATARS display.

The objective of the ATARS effort reported was the design of a traffic advisory service that complements the ground based resolution service while being compatible with the other applications being developed for the DABS data link. The main technical issue was the construction of a set of message formats that provides the pilot with all information he requires while minimizing data link loading. Furthermore, this message set had to support a wide spectrum of onboard equipment, from a simple ring of lights to a sophisticated graphics system.

17. Key Words	18. Distribution Statement
Air Traffic Control Advisory Resolution Service Discrete Address Beacon System Data Link Avionics	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22.
Unclassified	Unclassified	150	

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1.0 PROJECT OVERVIEW

The Automatic Traffic Advisory and Resolution Service (ATARS) is a ground-based collision avoidance system which has evolved from the earlier concept of Intermittent Positive Control (IPC). It utilizes surveillance data from the Discrete Address Beacon System (DABS) [1], computes traffic advisories and collision warnings using a ground computer independent of the ATC computer system, and delivers these messages to aircraft via the DABS data-link. ATARS provides both a traffic advisory and a resolution (collision avoidance) service to aircraft equipped with a DABS transponder, an altitude encoder (mode C), and an ATARS display.

Flight testing of the original IPC algorithm demonstrated the usefulness of the traffic advisory portion of IPC (also called the Proximity Warning Indicator or PWI) as an aid to visual acquisition. However, the flight tests also pointed up the potential benefits that might be derived from a more complete traffic advisory service, especially one that could aid the pilot in threat assessment as well as in visual acquisition.

1.1 Background

The 1969 DOT Air Traffic Control Advisory Committee (ATCAC) recommended the development of DABS to obtain improved surveillance and an integral data link. It also recommended the development of a ground based collision avoidance system based on DABS that would provide traffic advisories as well as commands to resolve hazardous encounters. The initial development of this IPC system was the responsibility of the MITRE Corporation. During 1974 to 1976 Lincoln Laboratory conducted a major flight test activity using the DABS Experimental Facility (DABSEF). The results of this effort were documented in a report [2] that defined deficiencies in the tested IPC system and recommended needed improvements to both the advisory and resolution functions. Now called ATARS, this collision avoidance system is undergoing redesign. MITRE is responsible for the improvements to the resolution service, while Lincoln Laboratory is responsible for the development of an improved traffic advisory service.

Two main results came out of the IPC test flight program. The first was that the Proximity Warning Indicator (PWI) service provided help to the pilots, producing a six-fold increase in the visual acquisition of proximate and threatening aircraft. The second, however, was that pilots felt the need for more specific information than simply the bearing and relative altitude zone provided by PWI. Without explicit information on aircraft range, heading, and velocity, the pilot was unable to make either a threat assessment or a determination of a safe maneuver. Since this additional information is

available in the ATARS ground computer, it was reasonable to conceive of redesigning the uplink messages to include it.

The objective of the Lincoln ATARS effort was the design of a traffic advisory service that complements the ground based resolution service and is compatible with the other applications being developed for the DABS data link. The main technical issue was the construction of a set of message formats that provides the pilot with all information he requires while minimizing data link loading. Furthermore, this message set had to support a wide spectrum of onboard equipment, from a simple ring of lights to a sophisticated graphics system.

The system design effort of the Lincoln ATARS program has now been completed. The first issue addressed was the determination of the set of information a pilot would require to properly evaluate each encounter. After the information content was defined, a set of messages for transmission of this information to the aircraft was designed. The formats of these messages were constrained by two main considerations: (1) efficiency of packing in order to minimize data link loading, and (2) ease of support of low end onboard displays. Complex displays, with sophisticated microprocessors, can handle any message class; unsophisticated equipment, though, can only be expected to handle a few message types, and the variables needed in each must be directly available in a usable format.

A development airborne graphics display system was built in order to support the validation of the traffic advisory service and other data link applications. This system, consisting of a microprocessor to process messages and a color weather radar CRT to display the encounter information, has been programmed and installed in test aircraft [3]. It is currently undergoing ATARS flight testing at the FAA Technical Center. Lincoln is completing a second version of display based on a less capable 3" CRT in order to support validation testing in general aviation class aircraft. The same microprocessor system already built will support this new display.

1.2 Traffic Advisory Service Objectives

The two main objectives of the ATARS traffic advisory service are: to aid the pilot in visually acquiring proximate and threatening aircraft, and to aid him in performing accurate threat assessment on those aircraft. The service will also provide blunder protection by providing information on nearby aircraft that would assist the pilot in avoiding maneuvers which could create a collision hazard.

See-and-avoid has been the primary protection against mid-air collisions for pilots flying under both Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) in Visual Meterological Conditions (VMC). At present, controllers provide "traffic" advisories to VFR on a work permitting basis and "safety"

advisories to IFR pilots on a first priority basis. In either case, however, advisory issuance is contingent upon the awareness of the controller of the unsafe or threatening situation. Thus, pilots may not always receive all of the advisories they desire, and those received may not always be received in time.

The ATARS traffic advisory service will improve the see-and-avoid approach in the following respects:

1. all necessary advisories will be provided on a full-time basis independent of controller workload

2. most advisories will be provided early enough for the pilot to have sufficient time to assimilate the information and safely react to the situation

3. the potential for human error, caused by controllers having insufficient time to study each situation, will be eliminated

4. more information with greater accuracy will be provided on each situation than is presently available from the controller

The additional and more timely information is especially important since increased aircraft velocities will require accurate threat assessment at the limits of visual acquisition.

1.3 Scope

This document presents a unified ground/data link/airborne system for implementing the traffic advisory service of ATARS. The purpose of this service is to inform pilots of all potential conflict encounters that exist, or may develop, due to nearby aircraft and to aid him in avoiding blunders. Threat and proximity advisories are transmitted from ground sensors to the aircraft via the DABS data link as COMM-A messages. The resolution service of ATARS, which supplies advisories to pilots to help avert serious encounters, will not be described in this document.

The key blocks of the coordinated ATARS system are:

1. a ground tracker to predict future positions of all aircraft

2. rules for determining when threat and proximity advisories are required

3. a set of uplink messages that can provide all information required by all classes of ATARS users

4. rules for determining when to send each uplink message

5. a range of onboard equipments to present ATARS information to the pilot

6. algorithms for each such onboard system to define how each ATARS message is processed and displayed

This document will cover in detail all of these areas. The detailed onboard algorithms apply only to the graphic display system built by Lincoln but are representative of those that would be used in any similar sophisticated display.

2.0 ATARS GROUND SYSTEM

Nearly all of the additional quantities required by the ATARS traffic advisory service already existed in the IPC computer. Thus, few ground algorithm modifications were needed to support the improved traffic advisory service. This chapter presents and describes the changes that were required. Since MITRE is responsible for modifying the ground system to meet these requirements, no implementation details are provided.

2.1 Traffic Advisory Determinations

An ATARS traffic advisory message is generated for two different types of encounters: proximity and threat. Proximity messages, previously named ordinary PWI's, inform the pilot of all aircraft in the nearby airspace not currently viewed as threats. Threat messages, previously called flashing PWI's, are only sent for aircraft whose present flight path would bring them into conflict with the subject aircraft. The latter encounters are thus more urgent, and may require pilot action or flight constraints to avoid collision. More serious threat encounters are accompanied by resolution messages, previously called commands.

A proximity advisory is generated for any aircraft whose horizontal and vertical separations from the subject aircraft are both within specified limits. The vertical limit is always 2000 feet, but the horizontal limit (H) is a function of the two aircraft speeds:

$$H' = SQRT\ [2*900*(V_1^2 + V_2^2)]\ nmi$$

V_1, V_2 in nmi/sec

$$H = Max\ (2, H')nmi$$

This limit grows linearly with aircraft speeds, going beyond the minimum 2 nautical miles when both aircraft exceed 120 knots and being 5 miles when both aircraft are traveling at 300 knots.

A threat advisory, rather than a proximity advisory, is sent when the other aircraft is closing on the subject aircraft, and the expected time until closest approach (τ) is within 50 seconds. The critical time is calculated as $\rho/\dot{\rho}$, where ρ is the inter-aircraft range and $\dot{\rho}$ is the component of the relative velocity along the relative bearing angle. Although the actual criteria needed to create a threat situation are quite complex, an approximate simplification is that all of the following three conditions must be met:

1. the horizontal component of τ is within 50 seconds, or the current horizontal separation is less than 1.2 miles; and

2. the vertical component of τ is within 50 seconds, or
   the current vertical separation is less than 1000 feet; and

3. the projected closest approach range is less than 1.2 mile.

These numbers are all experimental and subject to change.

A more critical threat situation also triggers a resolution advisory, which is a command the pilot is instructed to follow in order to avoid a collision or near miss. Resolution advisories can be positive (e.g., climb or turn right), negative (e.g., don't descend or don't turn left), or vertical speed limits (e.g., limit climb to 500 feet per minute). More than one such advisory can exist at a time if the situation complexity so warrants. The issuance of these advisories is controlled by the same three criteria as the threat advisory, although with smaller values of τ and separation.

2.2 Most Critical Encounter

Many of the unsophisticated displays to be employed for ATARS will only be able to present complete information on the most critical encounter. Rather than requiring such low cost displays to have the computational power to determine which encounter is most important whenever two or more exist, the ground system is required to flag the most critical encounter each scan via the bit provided for that purpose in each position message.

In addition, the ground is required to list all other encounters in order of priority. This ordering becomes relevant on any scan in which the data link capacity is exceeded by the number of messages, ATARS and non-ATARS, waiting for transmission. In such cases, the ATARS encounters should be transmitted in order of importance.

Both of these functions are performed by introducing a scoring function for encounters. The first scoring rule is that any threat encounter associated with a resolution advisory outranks any threat encounter not associated with such an advisory, and that any threat encounter outranks any proximity encounter. Encounters within each of the three classes are then scored as follows, where a lower score implies a higher ranking:

Proximity:
    score = range = horizontal separation + 5 times vertical separation

Threat (either class):
    score = horizontal τ
        ties are broken by range (defined as above)

Not all threats are detected via a horizontal τ. For those found from the maneuvering target logic, a pseudo τ is computed as horizontal range divided by the sum of the aircraft velocities; for diverging threats, τ is set to a large constant (and thus range selects between multiple ones).

The most critical encounter will generally be the one with the lowest score. However, once an encounter is labelled most critical, it should remain so for at least two scans. This requirement prevents the screen flicker that would occur by rapid changes of most critical encounters, and should provide the pilot with enough time to assimilate the encounter data. Thus, the rules for one encounter replacing another as the most critical are the following:

1. an encounter of one class (defined above) will always replace one of a lower class

2. an encounter must be most critical for two or more scans before it can be replaced by one of the same class

2.3 ATARS Tracker

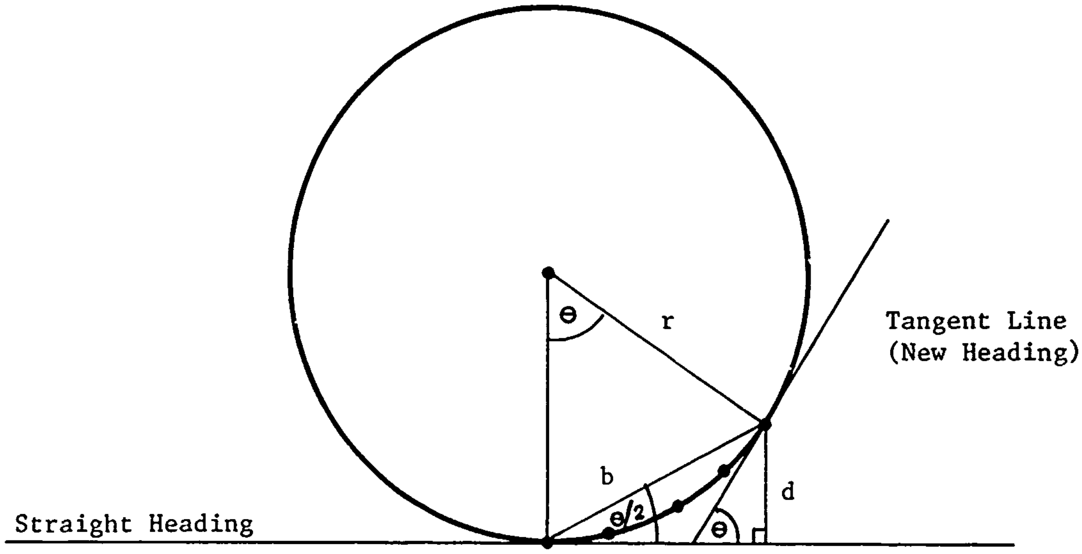
The tracker used for ATARS screening and prediction is a smoothed X-Y tracker with turn detection. The smoothing constants have been selected to provide best estimates of the heading and velocity of each aircraft, since these quantities are more important than position for ATARS functions. The turn detector indicates whether the aircraft is in a turn. If a turn is detected, different smoothing constants are employed to better match the changed flight dynamics, and future projections are based on modifications to the current heading.

The basic tracker for ATARS, originally designed for IPC, will support the expanded traffic advisory service if one improvement is added: an estimate of the actual turn rate, not just a yes/no turn indication. This quantity, provided to sophisticated users, permits their displays to be accurately updated even when ground data is missing. Since a cross-track deviation is already being computed, the additional turn rate quantity can be calculated with a minor mathematical addition. Figure 1 presents the geometry that applies at the beginning of a turn, along with the turn rate equation. By employing the heading that existed two or more scans ago for the cross track deviation computation, rather than the most recent one, a more accurate turn rate can be found. This modification simply requires extra track file storage for additional heading fields.

Once a turn has been established, future turn rate calculations can be made just by noting the heading change that occurs each scan after the tracker has performed its turn state smoothing. Heading values are required in any event for traffic advisories, so no additional work is needed. The turn ends when no further heading change is noted.

2.4 Ground Processing Requirements

The ground system must maintain all information that is required to support the various ATARS functions. Thus, the positions of all aircraft must be kept to determine proximity encounters. In addition, the projection parameters required to locate threat encounters, namely aircraft headings,



$$
\begin{aligned}
b &= 2r\ \mathrm{SIN}\ \theta/2 \\
d &= b\ \mathrm{SIN}\ \theta/2 \\
&= 2r\ \mathrm{SIN}^2\ \theta/2 \\
&\approx 2r\ \theta^2/4 \text{ for small } \theta
\end{aligned}
$$

$\theta = \omega t$ $\qquad$ t = Time for n Scans

$r\theta = vt$ $\qquad$ v = Velocity

$$
\begin{aligned}
d &= 2(vt)\ \frac{\omega t}{4} \\
&= 1/2\ v\ \omega t^2
\end{aligned}
$$

$$\boxed{\omega = \frac{2d}{vt^2}}$$ Turn Rate

Fig. 1. Turn Rate Computation.

turns, and velocities, must be maintained. Finally, all information that is transmitted in any uplink message (as defined in section 4.1) must be present in the ground computer or be computable from quantities that are.

Each time the ground system determines that a new encounter has begun, either proximity or threat, it must assign a track number to the encounter and commence the transmission of the appropriate uplink messages. The ground must then check the status of this encounter every scan, and continue the message stream for that track number as long as the geometric relationship of the two aircraft satisfies the advisory rules. Finally, when the encounter terminates, one further message must be sent, the end message. The track number is then available for use with another encounter.

The implication of these rules is that the ground must maintain encounter pair records, with track numbers, on all proximity and threat encounters, instead of just on resolvable encounters as in IPC. The transmission of an end message after the encounter has terminated (to inform sophisticated users they may drop their file) is also a new requirement. Both of these augmentations, though, are simple and straightforward to implement.

In order to provide a meaningful display, the number of encounters presented to the pilot must be limited to a reasonable number. Thus, the track number has been implemented as only a 3-bit quantity. Even the eight encounters this provides is probably beyond the useful bound, and could lead to more information than can be assimilated by the pilot. The ground system must insure that all threats are given track numbers, even if ongoing proximities are lost in the event of more than eight encounters. Also, it must order the uplink messages, most important to least important, so that any not delivered on a scan are the least critical.

2.5 Multisensor Handoff Procedures

When ATARS operates in a multisensor environment, aircraft will frequently cross sensor coverage boundaries during the time they are receiving traffic advisories, even when they are under resolution advisories. Thus, MITRE has defined handoff logic for the ATARS system. This logic uses three zones of coverage, as illustrated by Figure 2, with three different methods of ATARS service. This section outlines the sequence of actions that occur for the normal order of transition shown in the diagram; other situations are handled by similar algorithms.

Initially, the aircraft is processed by the ATARS logic of sensor A, and that sensor's data link is used to uplink the ATARS messages. When the uplink boundary is crossed, message transmission responsibility is turned over to sensor B. However, the sensor A ATARS logic is still controlling the encounters, and routing the messages to sensor B. Finally, when the ATARS boundary is crossed, sensor B becomes responsible for both the formation and transmission of the ATARS messages.

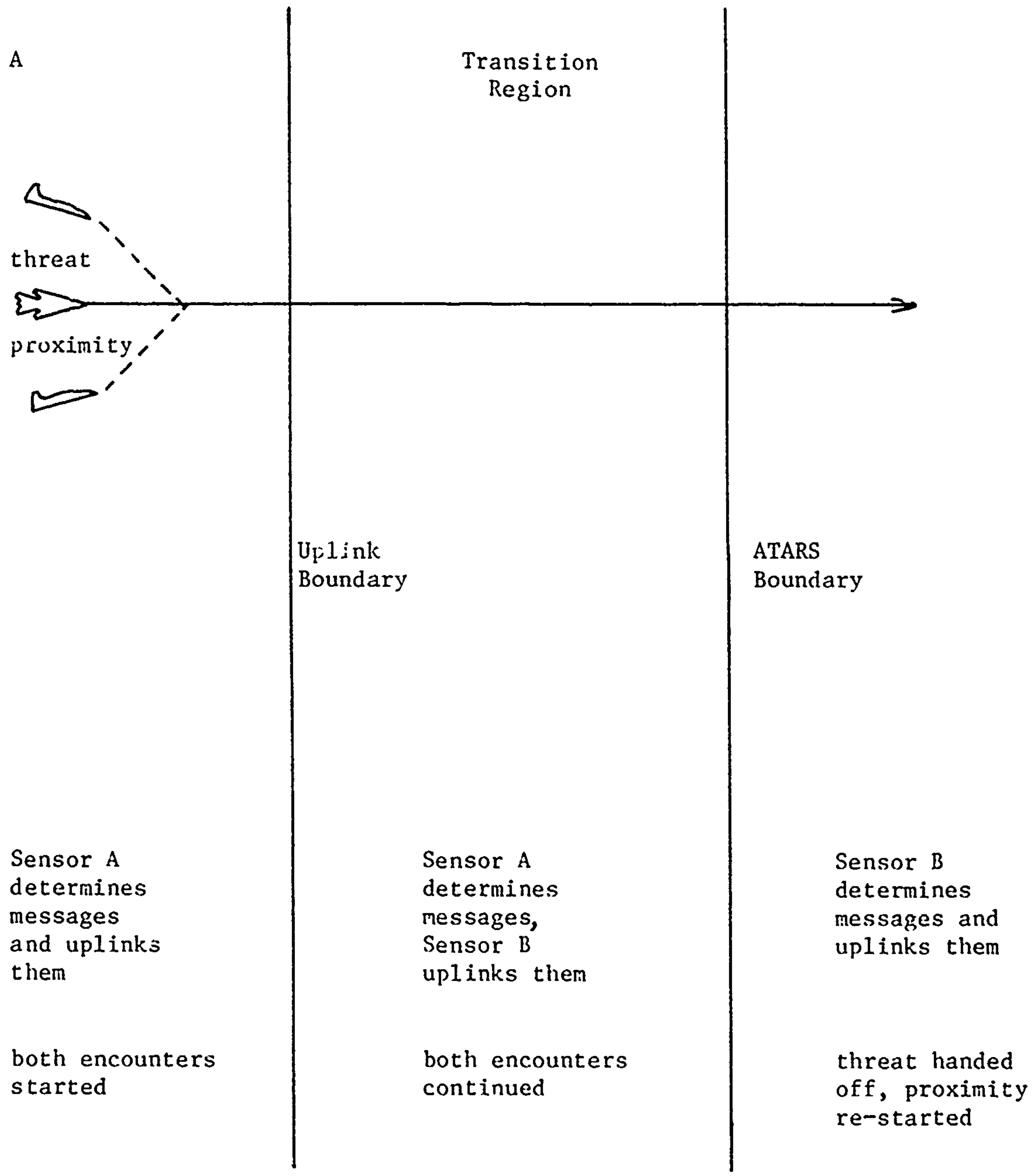


Fig. 2. Handoff Geometry.

A completely smooth transition of ATARS authority can only occur if sensor A were to send sensor B all its data on all open encounters. The current ATARS system only sends such information, in the form of conflict tables, if a resolution advisory is in effect. Thus, only some threat encounters, and no proximity ones, would be covered. Increasing the requirement to handle all encounters could add a substantial load to the inter-sensor communications link. However, by only requiring all threat encounters to be handed off, and ignoring the less critical proximity encounters, the increased load should be negligible. The change needed in the existing ATARS ground logic for this method of operation is the construction and maintenance of conflict tables for all threats, not just those requiring resolution. This modification can be made at a later date if found to be desirable.

A minor modification to the ATARS conflict table format is required to permit the avionics equipment to smoothly handle these transitions. Namely, the track number used by sensor A in its uplink messages has to be included. Then sensor B can employ this same number for the encounter, and onboard display continuity is assured.

3.0 ATARS DATA LINK SYSTEM

The medium used for transmitting information from the ATARS ground computer to the onboard display system is the DABS data link. The basic data link entity, the COMM-A, can accommodate a message as large as 48 bits. Thus, if the totality of ATARS information is divided into 48 bit segments, it can be sent to the aircraft via a series of COMM-A's.

The more information about each encounter sent to the aircraft, the more complete and accurate the display can be. Unfortunately, the number of COMM-A's available to ATARS on each scan is limited. Thus there is a benefit attached to reducing the information set. Less important information, quantities nearly constant over the encounter, and quantities calculable onboard are all subject to deletion.

This section discusses the ramifications of the information/link-occupancy tradeoff.

3.1 ATARS Message Philosophy

A variety of different message formats, with corresponding message utilization protocols, can be employed to implement ATARS. The proper choice of system can be made only after the following two system philosophy questions have been answered:

1. should all ATARS users be provided with the same information, or should classes of users be defined, with sophisticated users receiving more data than unsophisticated users?

2. should complete information be provided for both proximity and threat encounters, or should proximity encounters be less fully specified than threat encounters, or should all encounters be specified by the minimum data subset?

Expected data link loading conditions play a critical role in these decisions, although the role of ATARS in the spectrum of ATC functions is also important.

The main advantage of treating all users alike is system simplicity: the ground needs only one message protocol, and no method is required for determining aircraft user type. Its disadvantage is that either unsophisticated users are sent more information than they require, and hence some data link capacity is wasted, or sophisticated users are denied some useful information, and hence some display accuracy is sacrificed.

Defining two or more ATARS user classes permits the tailoring of messages to the user needs. In particular, users desiring only resolution service and not equipped for traffic advisories would require almost no messages, while unsophisticated users could be serviced by shorter messages than sophisticated ones. This method of operation, of course, complicates the ground system, and leaves ATARS open to more and more classes being

introduced. More important, though, it could lead to severe problems if an error were made in an aircraft user type determination. To prevent dangerous onboard misinterpretation of information, or loss of required data, the messages themselves must be made fail-safe (or at least fail-soft). This means that a user of one class, receiving a message meant for a user of a different class, could still produce a correct and usable display. This requirement eliminates the possibility of suppressing traffic advisories to some users, since any aircraft erroneously typed as a resolution-only user would receive no advisories. Sophisticated and unsophisticated users, though, can be supported in a fail-soft manner as described below.

A proximity encounter, by definition, is less critical than a threat encounter. Thus, it is not unreasonable to provide less detailed position and motion information in its message. Furthermore, the presence of resolution advisories when a threat becomes dangerous means that some loss of accuracy even in threat encounters can be tolerated. Thus, any of the three alternatives suggested above in question 2. may be proper, and studies of system performance and data link loading are required before an optimum choice can be made.

3.2 Encounter Information Options

The ATARS data that must be transmitted to specify a proximity encounter is the current position and state of the proximate aircraft. As shown in the first column of Figure 3, if total available information is to be provided, one entire COMM-A message would be needed. However, as shown in the next column, by cutting back to the smallest acceptable data subset, only half a COMM-A would be needed. Therefore, two different proximity encounters could be described in a single COMM-A, and link loading would be reduced.

The minimum subset eliminates velocity, turn type, and vertical speed. As will be shown, the former is always given in the message at the start of an encounter and should change little during the encounter; the latter two are deemed of less importance to the pilot. The track number is also lost, thereby requiring a sophisticated user's onboard computer to perform positional correlation. Finally, a less precise heading is provided.

A sophisticated graphic display will present a relative motion picture for threat encounters, thereby helping the pilot to visualize the forthcoming changing geometry between his and the threat aircraft. Thus, a complete threat specification must include information on both the current position of the other aircraft and its projected position at the time of closest approach. As shown in the third column of the figure, this total set of information would require two full COMM-A messages. However, as shown in the last column, it is possible to define a basic set of threat information that would fit within a single COMM-A.

Message Field	Proximity Full Data	Proximity Basic Data	Threat Full Data	Threat Basic Data
Bearing	7	7	7	7
Altitude	5	5	8	8
Range	6	6	6	6
Heading	7	3	7	7
Control Bits	3	3	5	5
Track Number	3	-	3	3
Velocity	7	-	7	-
Turn Type	3	-	3	3
Vertical Speed	6	-	6	6
Miss Distance	-	-	3	3
Time to CPA	-	-	6	-
Altitude at CPA	-	-	5	-
Bearing at CPA	-	-	7	-
Own Heading	-	-	7	-
Total	47 bits	24 bits	80 bits	48 bits

CPA is closest point of approach.

Fig. 3. Encounter Information Options.

The basic subset has eliminated velocity, own heading, and all closest point of approach quantities other than miss distance. The former two are included in other message types sent less frequently. The closest point of approach quantities, on the other hand, are computable from the other data fields, although with potentially significant error. The Appendix provides the details of these computations, as well as their expected accuracies.

It should be noted that even the basic threat data is still far more complete than that provided for by the basic proximity set. This is in recognition of the more serious nature of threat encounters. If this were not considered relevant, and if relative motion displays were not required, then the same half COMM-A subset could be used for threats as for proximities.

3.3 Possible ATARS Message Protocols

This section defines four possible protocol systems that were considered for ATARS, for two user classes, that cover the range of systems implied by the previous section's options. The message formats to support these systems are detailed in the next chapter. By considering all the message types specified there, a decision on the "correct" choice can be postponed until tests have been run. Once a system is chosen, of course, it will be the only one employed.

Figure 4 presents the four sample ATARS protocol systems, using the encounter message requirements for their definition. A Single Proximity Message presents complete data on one proximity encounter, while a Dual Proximity Message presents basic data on two different proximity encounters; a Basic Threat Message presents the basic threat data subset, while the Supplementary Threat Message presents the remaining data for a complete threat specification. The first three systems treat all users equally, while the last one differentiates between sophisticated and unsophisticated users.

The first protocol system, named Full Information, employs, for all users, messages containing full information for all encounters, one for each proximity and two for each threat. Thus, any piece of information that could be employed by the onboard equipment is guaranteed to be present. This system, of course, requires more COMM-A transmissions than any of the others, as shown by Figure 5.

The second system, named Basic Proximity, provides only minimum information for proximity encounters whenever two or more exist, but still maintains full data for each threat. Again, all users receive the identical messages. This system requires fewer COMM-A transmissions than the previous one when multiple encounters exist.

ATARS Messages	Don't Know User Class						Know User (Fail-Soft)	
	Full Information (I)		Basic Proximity (II)		Minimum Information (III)		Matched Threat (IV)	
	Prox	Threat	Prox	Threat	Prox	Threat	Prox	Threat
Single Proximity	⊗							
Dual Proximity			⊗		⊗		⊗	
Basic Threat		⊗		⊗		⊗		
Supple-mentary Threat		⊗		⊗				

X = Sophisticated User

O = Unsophisticated User

⊗ = All Users

Fig. 4. ATARS Message Protocol Systems.

No. of COMM-A Messages
(See Fig. 4. for System Labels)

Active Encounter Situation	I	II	III	IV	
				Soph.	Unsoph.
1 Proximity	1	1	1	1	1
2 Proximity	2	1	1	1	1
3 Proximity	3	2	2	2	2
1 Threat	2	2	1	2	1
2 Threat	4	4	2	4	2
1 Prox, 1 Thr	3	3	2	3	2
2 Prox, 1 Thr	4	3	2	3	2

Fig. 5. Number of COMM-A Messages Per Scan.

The final single user class system, named Minimum Information, provides only the minimum data sets for all encounters, proximity and threat. Thus, this system requires the minimum possible number of COMM-A transmissions. However, since the closest point of approach calculations must now be performed onboard, more complex display software is required under this protocol.

The remaining system requires the ground to ascertain the type of ATARS user represented by each aircraft. However, as described in the next chapter, message formats are designed to be fail-soft. Thus, a user receiving the wrong type of messages will still be able to function properly.

The Matched Threat system sends full information on threats only to sophisticated users, with only basic threat data sent to unsophisticated users. All users, of both classes, will receive only basic proximity data. If only a small percentage of users are sophisticated, this system will require very few more COMM-A messages than the Minimum Information one. However, these few additional messages may well provide a major improvement for the sophisticated class of user.

Various other one and two user class systems could be defined. However, since this section was meant to be representative and not exhaustive, they will not be discussed here.

A key measure to be used in choosing the "best" system, as discussed next in the recommendations section, is the number of COMM-A messages each system requires for various combinations of active encounters. Figure 5 presented this data for a typical scan of each case. As discussed below, encounter starts and endings require special messages.

FAA studies of Automated Radar Terminal System (ARTS) tapes and runs of the Air Traffic Control Simulation Facility (ATCSF) indicate that over 90% of all encounters will be proximities. Furthermore, except in very dense environments, only one or two such encounters will exist at any time. All of the systems are identical for a single proximity case, so Figure 6 presents the different time lines that apply for a two proximity situation. The special start and end messages are discussed in the next chapter.

The systems also differ in their time lines when a threat encounter is present, as shown in Figure 7. Again, the start and end scans are discussed in the next chapter. Since proximity and threat encounters cannot be combined into joint messages, the presence of one or more proximity encounter along with the threat would simply add messages to the time lines.

3.4 Recommendations

Subject to flight test verification, it appears that the basic proximity data set should provide pilots with sufficient data on proximate aircraft.

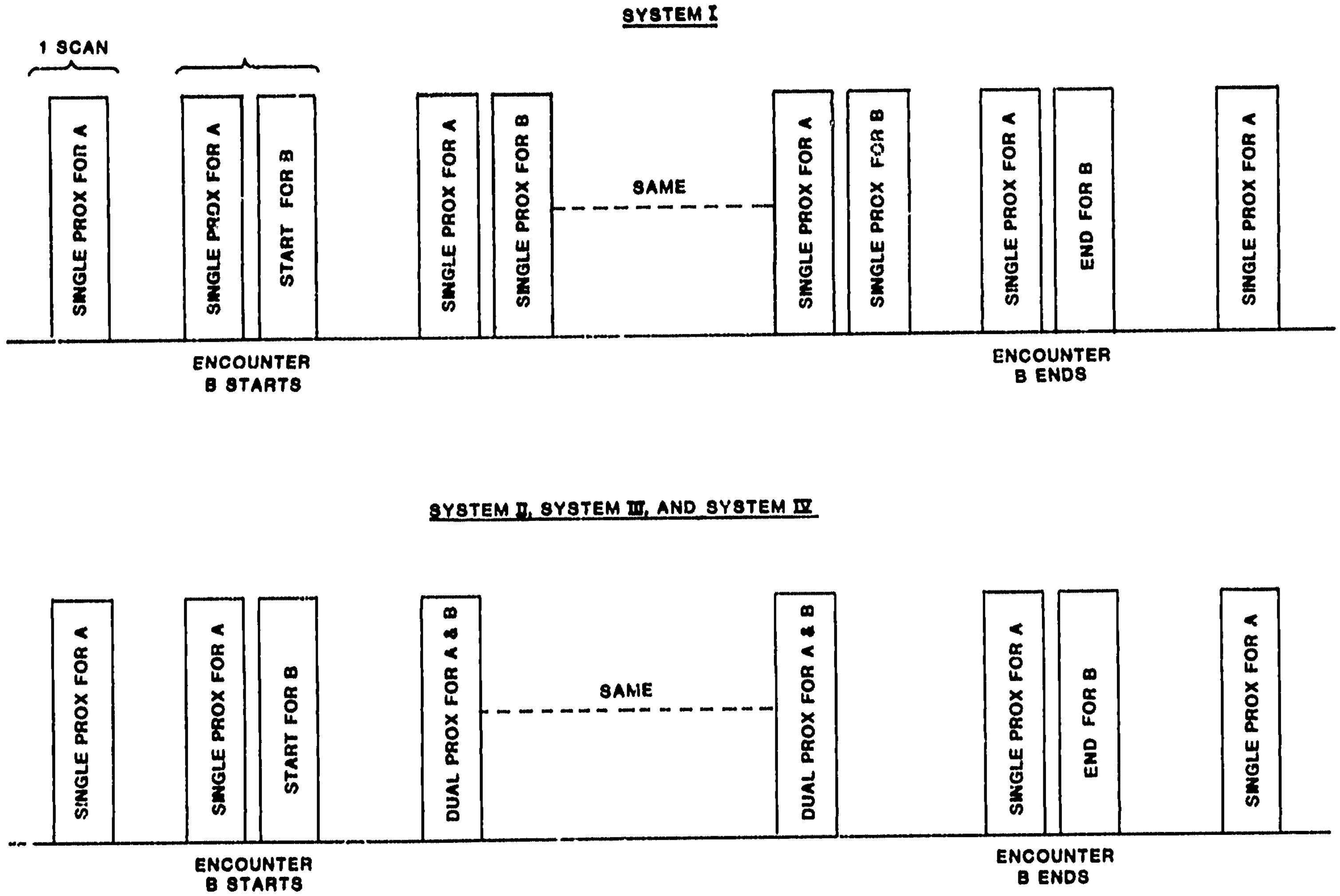


Fig. 6. Handling A Second Proximity Encounter.

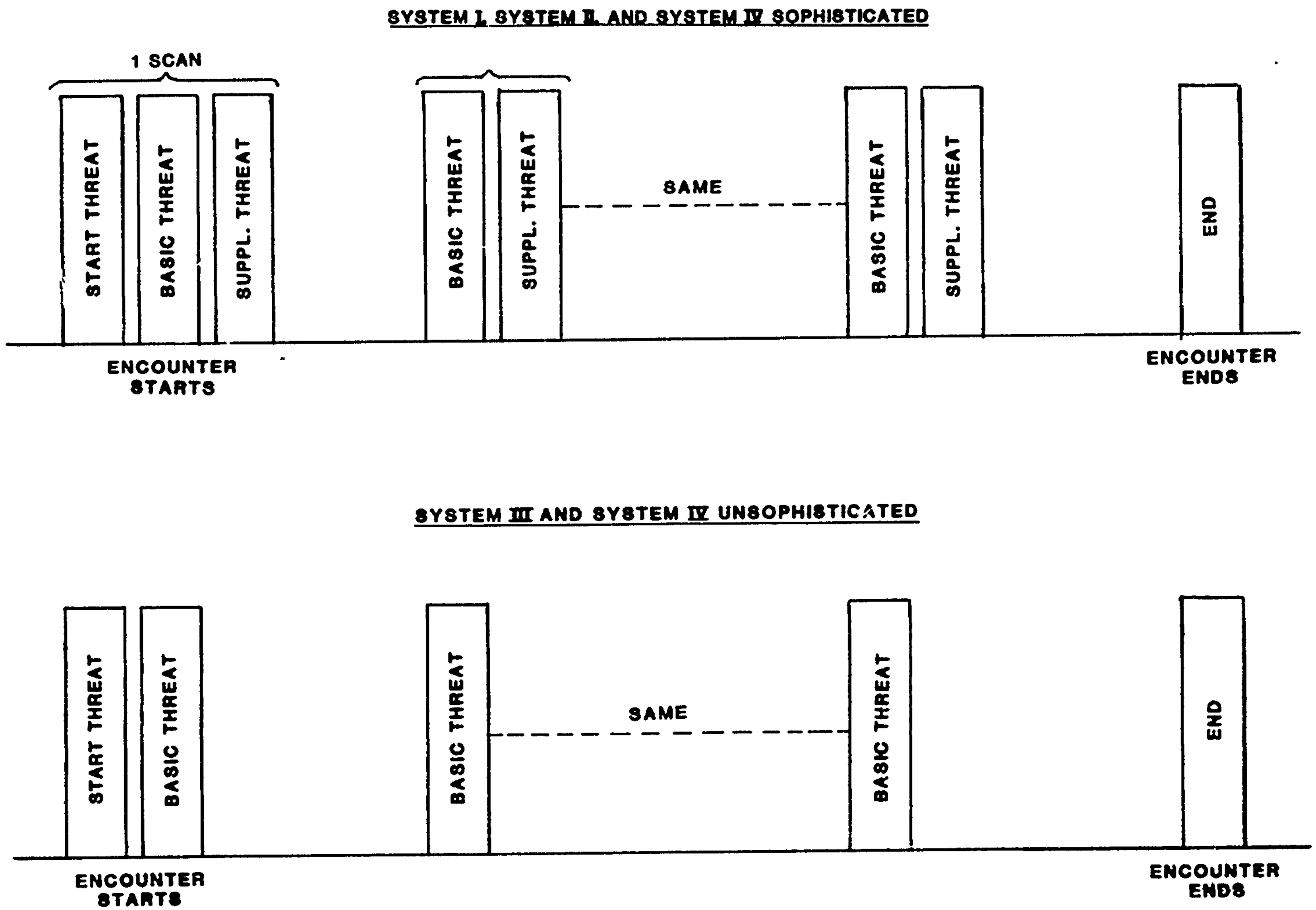


Fig. 7. Messages During A Threat Encounter.

Also, if onboard calculations of the time to, and position of, the point of closest approach for threat aircraft provide accurate results, the basic threat data set will supply all information necessary for threat aircraft displays. Thus, if both of these suppositions are proven true, the Minimum Message System is the optimum one to choose for ATARS. In particular, it possesses the following distinct advantages over the others:

1. it doesn't require user class determination, with its inherent error possibilities,

2. it is minimal in its COMM-A requirements, and performs significantly better in this aspect, than the others considered, as the encounter load grows and data link loading becomes more critical

Before a final choice was made, however, three factors were considered. These were:

1. data link loading and capacities
2. system flexibility
3. cost to general aviation users

The first issue was analyzed by MITRE [4]. System flexibility can imply many factors. One of the most important, though, would be the ability to define additional levels of user equipment beyond just sophisticated and unsophisticated. By selecting a system that treats all users equally, this becomes quite simple to do. With a two user system, though, all new classes would have to be mapped into one or the other of the defined ones if complexity is to be avoided. Finally, all options appear to be able to support the very simplest user displays, so general aviation cost is apparently not a selection factor.

Lincoln recommended the initial selection of the Minimum Information System for ATARS, and believes it should be employed for flight tests and submitted for avionics manufacturers comments. As noted earlier, the proposed messages can support any of the four system protocols considered. Therefore, one of the other three system protocols could be implemented if the Minimum Information System is found after flight testing to be insufficient for ATARS needs.

4.0 ATARS UPLINK MESSAGES

A large variety of information is required by the onboard ATARS computer and display in order for them to perform at full capability. Some of this information is the same for all encounters, some stays constant throughout an encounter, and some changes continually during an encounter. Also, proximity and threat encounters have different data needs. Thus, to match these characteristics, a number of different ATARS messages have been defined.

Each ATARS message is sized to fit within the 48 data bits of a DABS COMM-A. Since the major ATARS data sets, such as current aircraft position and basic threat data, consist of 24 bits, two such sets can fit within a COMM-A. This chapter first describes the data sets currently defined in the ATARS system now undergoing test. Then it presents the ATARS messages they combine to form, and the rules for selecting the proper ones to transmit. The final section discusses possible future additions and modifications to the message set.

4.1 ATARS Data Sets

The data sets that have been defined for initial ATARS testing are presented in the following paragraphs. All sets contain 24 bits so that any two can be combined into a single COMM-A message.

4.1.1 Own Data (Figure 8)

The Own Data Set is the only data set not tied to an encounter. It is transmitted on initial ATARS contact and updated subsequently when necessary. Unsophisticated avionics will ignore this message's presence.

For a sophisticated user, this data set is used to specify the parameters of motion of the subject aircraft: heading, velocity, and turn rate. These quantities can be displayed to provide the pilot a sense of confidence in the ground tracker. More importantly, if onboard instruments are tied into the ATARS avionics, the errors detected in these values can be used to correct the ATARS traffic advisories for aircraft crab angle. For example, if the own heading is off by 5°, then a 5° correction could be made to all bearing angles. Also, a sophisticated onboard computer will need own velocity and heading to compute the time and position of a threat encounter's closest point of approach.

The ATARS capability field is very important if different classes of users are defined for either the traffic advisory service (as discussed in the previous section) or the resolution service.

Currently planned DABS and ATARS multisite designs hope to ensure that only one sensor is providing ATARS messages to any aircraft at one time. Some operational modes and various failure modes, however, can interfere with this

Field	Bits	Interpretation
Own Ground Track Heading	7	2.8125° lsb Referenced to magnetic north of DABS site
Own Ground Track Speed	7	10 knot lsb
Own Ground Track Turn Rate	4	1°/sec lsb (Two's Complement with Right Positive)
Own ATARS Capability	2	4 levels possible (only 01 used at present)
Seam Bit	1	Multi (1) or Single (0) ATARS sites can uplink data
Antenna Scan Period	3	1 sec lsb added to 4 seconds (thus 4 to 11 seconds possible)
TOTAL	24	

Fig. 8. Own Data.

assignment process. The seam bit informs the onboard computer whether unique coverage can be guaranteed at the current location of the aircraft. If true, message track numbers provide unique encounter labels; if not, onboard positional correlation of messages to encounters will be required by sophisticated users.

Finally, the scan period provides the timing data that is required by sophisticated avionics to compute positional rates of change. Thus, it permits such avionics to coast encounters whose messages are missing for a scan.

4.1.2 Position Data (Figure 9)

The Position Data Set is used for all encounters, proximity or threat, to specify the current position of the other aircraft within the advisory airspace of the subject aircraft. As such, it is the key ATARS data set. In fact, except for resolution advisories, it supplies all the information a simple unsophisticated display would need for its presentation.

The position attributes supplied by this data set are the relative bearing, relative altitude, range, and coarse absolute heading of the encounter aircraft. The clock bearing and altitude zone methods of presenting the data were chosen to permit direct implementation of light rings as in an IPC type display [2]. The fine bearing provides more sophisticated displays with the greater accuracy required for numerical or graphic displays, particularly if trail information on a CRT is desired. Absolute heading is presented to match normal system protocol; relative heading for graphic displays can be calculated by subtraction of the own heading provided by the previous data set.

The Position Data Set also supplies information on the ATC control status and ATARS equipage of the other aircraft. These items help the pilot judge who will assume control of resolving the conflict and aid in his evaluation of the situation. Finally, an indication is provided as to whether this encounter is the most critical currently existing for the aircraft. This aids simple avionics in choosing the encounter to display.

4.1.3 Supplementary Proximate Data (Figure 10)

The Supplementary Proximate Data Set provides information on the motion of a proximity encounter aircraft whose current position was defined in the Position Data Set. This information will be useful for sophisticated ATARS users in two ways: it will permit a more complete graphic specification, and it will permit accurate positional coasting in the absence of new data link messages. The motion quantities provided by this data set are velocity, turn type indication, and vertical speed. In addition, a finer heading and an encounter track number are provided. The use of the track number is discussed in section 4.2.1.

Field	Bits	Interpretation
Clock Bearing (CB)	4	1 o'clock (0001) through 12 o'clock (1100)
Fine Bearing (FB)	3	Bearing to target = [(CB) - 1/2] x 30° + (FB) x 3.75°
Altitude Zone	2	Bit 1: Equal or above (1) or Below (0) Bit 2: Co-altitude (0 to 500') (1) or Not (600' or more) (0)
Relative Altitude (RA)	3	If Co-altitude: 100' lsb If Not Co-altitude: 200' lsb beyond 600' (thus 600' to 2000')
Range	6	0.2 nm lsb
Coarse Heading (CH)	3	N(000), NE(001), thru NW(111)
ATC Control	1	Controlled (1) or Not Controlled (0)
ATARS Equipped	1	ATARS equipped (1) or Not (0)
Most Critical Flag	1	Most critical advisory (1) or Not (0)
TOTAL	24	

Fig. 9. Position Data.

Field	Bits	Interpretation
Track Number	3	0 through 7
Fine Heading (FH)	4	Heading of target = [(CH) - 1/2] x 45° + (FH) x 2.8125° [Note: CH is contained in position data]
Velocity	7	10 knot lsb
Turn Type of Aircraft	3	Bit 1: Turn (1) or Straight (0) Bit 2: Right (1) or Left (0) Bit 3: Strong (1) or Weak (0)
Vertical Speed of Aircraft	6	200 FPM lsb (Two's Complement with positive upward)
Spare	1	Set to Zero
TOTAL	24	

Fig. 10. Supplementary Proximate Data.

This supplementary information is transmitted currently only when 24 bits are available in an existing ATARS message, such as would normally be the case with only a single proximity encounter present. However, the Full Information protocol described in the previous chapter would have required it to be sent for all encounters.

4.1.4 Start Proximity and End Encounter Data (Figure 11)

The Start Proximity and End Encounter Data Sets are actually alternate interpretations of the same data set, controlled by whether the first bit is set to '0' or '1' respectively. Both sets are intended for sophisticated users only, and help them to control their internal encounter file records.

The Start Proximity Data Set signals the start of a proximity encounter and supplies the track number assigned to it by the ground. Section 4.2.1 describes in more detail the use of this number. Also, this data set provides the velocity of the encounter aircraft, which is the most important aircraft attribute missing from the Position Data Set. Thus, even if no Supplementary Data Set is ever transmitted, a reasonably accurate value of velocity will be known. Finally, room exists for aircraft identification data, such as type or size; at present, this field is undefined.

The only field used in the End Encounter Data Set is the track number. When this set is received by a sophisticated user, it knows to cancel the corresponding encounter file and remove the encounter, proximity or threat, from the display. This set is given lowest priority, since sophisticated avionics can automatically cancel encounters not updated from the ground. Also, if the track number is immediately needed by the ground for a new encounter (all other numbers being active), the data set is not employed. Instead, a start message with the track number is sent for the new encounter; the avionics, recognizing this number reuse, will perform as if the end message had been generated.

4.1.5 Basic Threat Data (Figure 12)

By definition, a threat encounter is more critical than a proximity encounter. Thus, the Basic Threat Data Set has been provided to supply the additional information required for accurate threat evaluation and assessment. This information is of three types: more exact current position, aircraft motion, and predicted miss distance.

Four of the fields in this data set, namely fine heading, turn type indication, vertical speed, and track number, were also present in the Supplementary Proximate Data Set. As discussed there, they provide a more complete description of the aircraft's current state of motion and permit coasting the display in the absence of uplink messages. In addition though, in conjunction with the horizontal miss distance field, they permit the complete calculation of the time and location of the closest point of approach of the threat aircraft by sophisticated onboard computers (see the Appendix).

Start Proximity:

Field	Bits	Interpretation
Sensor Termination	1	Set to 0
Velocity	7	10 knot lsb
Track Number	3	0 through 7
Aircraft Abbreviated Data	13	Currently undefined
TOTAL	24	

End Encounter:

Field	Bits	Interpretation
Sensor Termination	1	Set to 1
Spare	7	Not used
Track Number	3	0 through 7
Spare	13	Not used
TOTAL	24	

Fig. 11. Start Proximity and End Encounter Data Sets.

Field	Bits	Interpretation
Horizontal Miss Distance	3	0.2 nm lsb
Vertical Speed of Threat	6	200 FPM lsb (Two's complement with positive upward)
Relative Altitude Extension (RAE)	3	500' lsb RAE is added to the 2000' relative altitude provided by RA in position data (Fig. 9) [If RA < 2000', RAE=0]
Fine Heading (FH)	4	Heading of threat = [(CH) - 1/2] x 45° + (FH) x 2.8125° [Note: CH contained in position data (Fig. 9)]
Turn Type of Threat	3	Bit 1: Turn (1) or Straight (0) Bit 2: Right (1) or Left (0) Bit 3: Strong (1) or Weak (0)
Track Number	3	0 through 7
First Time Threat Data Transmitted	1	First time (1) or Not (0)
Commanded Bit	1	Threat is receiving resolution advisory (1) or Not (0)
TOTAL	24	

Fig. 12. Basic Threat Data.

Even unsophisticated users can make threat assessments from this data set as the miss distance by itself indicates the severity of the threat and hence the need for action. Also, the commanded bit informs the pilot whether the other pilot is receiving an ATARS resolution advisory coordinated with his, and thus whether or not they will be acting in concert to avoid a collision. Finally, the first time threat data transmitted bit can be tied to an audible alarm to announce the start of the threatening situation.

Threatening aircraft can be more than 2000 feet in altitude from the subject aircraft if either or both have large altitude rates. Thus this data set also provides an altitude extension field which, combined with the Position Data Set field, permits altitude differences as much as 5500 feet to be represented.

4.1.6 Start Threat Data (Figure 13)

The Start Threat Data Set, transmitted on the first scan on which a threat situation exists, is identical except for the first bit in both format and interpretation to the Start Proximity Data Set. This first bit specifies whether a new encounter has arisen or whether an existing proximity encounter has now transitioned to threat status. In the latter case, the information in this data set was already provided by the Start Proximity Message. Thus, if no changes have occurred (particularly in velocity), this data set can be omitted.

4.1.7 Resolution Data* (Figure 14)

The Resolution Data Set is used to convey the ATARS resolution advisories to the aircraft. This data set is necessary for ATARS only until the ATARS/BCAS interface protocol becomes operational and the Resolution Advisory Register (RAR) is implemented. At that time, a separate set of RAR messages will be used to transmit the resolution advisories.

The first 11 bits of the data set present the set of resolution advisories for the aircraft. Any '1' among the first 8 bits indicates the existence of the corresponding advisory. Thus, for example, 10000010 is decoded as turn right and don't climb. The last 3 bits, taken as a group, specify a single vertical speed limit advisory as defined in the figure.

The first time transmitted bit is set whenever the resolution state changes, either due to the addition or subtraction of an advisory. This bit is intended to actuate an audible alarm to alert the pilot of the change. Finally, the track number is used to indicate the encounter that has necessitated the advisories. If multiple encounters are involved, one at random will be chosen for this field.

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*The addition of the Resolution Advisory Register to coordinate BCAS and ATARS activities will require the message to be redefined. It is included here for completeness since it was used in the initial ATARS test system.

Field	Bits	Interpretation
Continuation	1	(1) Track Number Exists from Previous Proximity State (0) New Encounter
Velocity	7	10 knot lsb
Track Number	3	0 through 7
Aircraft Abbreviated Data	13	Currently undefined
TOTAL	24	

Fig. 13. Start Threat Data.

Field	Bits	Interpretation
Resolution Advisory	11	See Below
First Time Transmitted	1	First Time (1) or Not (0)
Track Number	3	0 through 7
Spares	9	Not used
TOTAL	24	

Bit position in 11-bit field	Advisory Implied when set
1	Turn right
2	Turn left
3	Climb
4	Descend
5	Don't turn right
6	Don't turn left
7	Don't climb
8	Don't descend

Bits 9, 10, 11 of 11-bit field	Advisory Implied
000	No VSL
001	Limit climb to 500 feet per minute (FPM)
010	Limit climb to 1000 FPM
011	Limit climb to 2000 FPM
100	Limit descent to 500 FPM
101	Limit descent to 1000 FPM
110	Limit descent to 2000 FPM

Fig. 14. Resolution Data.

4.2 ATARS Message Combinations

It is possible to create a large number of ATARS COMM-A messages by combining various pairs of the data sets just described. This section describes the pairings presently defined and under test in the first phase ATARS system. Figure 15 lists these messages along with the A-Definition Subfield (ADS) code for each COMM-A message [5]. Only eight ADS codes are currently in use for ATARS (although more are available), so some sharing of codes between different messages was required. In each such case, though, a bit within the message field differentiates between the alternatives. In particular, the first message bit in an ADS 26 message differentiates 26_0 and 26_1 messages, while the last bit in an ADS 31 message serves to differentiate 31_0 from 31_1.

4.2.1 Onboard Tracking

All ATARS messages other than the own message are employed only when an encounter exists. When the ground determines that a new encounter has commenced, it assigns a track number to it which is maintained throughout its duration. A sophisticated user could use this track number in every message so that messages can be correlated from scan to scan and used to maintain an onboard encounter file. However, since unsophisticated users do not require track numbers for proper operation of their displays, the track number is not part of the essential data base for an encounter, and thus is not included in the Position Data Set.

A sophisticated user, however, can still maintain track identity. The first message transmitted for any encounter contains a Start Data Set. Since this set contains a track number, the user will be able to initiate a file. Also, the last message sent for any encounter contains the End Data Set, which also has the track number. Thus, the user will know when to terminate an encounter file. Whenever the encounter is a threat, the Basic Threat Data Set, with track number, is transmitted each scan. Finally, whenever the encounter is the only proximity existing, and for some multiple proximity situations, the single proximity message will be employed for the encounter, and it contains the track number. Thus, only in the case that the user receives a dual proximity message will the track number not be supplied. By correlating on position with the active encounter files, proper assignment of the two proximity messages can be made.

4.2.2 Own Messages (ADS 24, 25, or 31_0)

The own data is employed by sophisticated users for various onboard calculations as described earlier. Thus an own message is required whenever any of the following conditions apply:

Message	ADS	Data Set 1	Data Set 2
Own	24	Own	-
Own Plus Proximity	25	Position	Own
Start Proximity	26_0	Start Proximity	Position
End Encounter	26_1	End Encounter	Position
Dual Proximity	27	Position	Position
Single Proximity	28	Position	Suppl. Proximate
Start Threat	29	Start Threat	Own
Threat	30	Basic Threat	Position
Own Plus Supplementary	31_0	Own	Suppl. Proximate
Resolution	31_1*	Resolution	last bit = 1

*THE RAR WILL USE A DIFFERENT ADS FOR RESOLUTION ADVISORIES.

Fig. 15. ATARS Message Definitions.

1. the seam condition has changed

2. the own heading or own velocity being employed onboard differs from the current ground value by more than a parametric value

These conditions insure accurate data is available to sophisticated users.

It should be noted that the Own Data Set contains a heading turn rate field. Thus, the onboard computer can track through a constant turn without ground support; only messages at the start and end of turns are required. In fact, the reason for including the turn rate field was just to reduce the number of own messages that would be needed solely for new heading information.

Since only 24 bits of own data exist, the remaining 24 COMM-A bits are free for other use. Three own messages are defined, as shown in Figure 15, in which these bits are used for proximity position data (ADS 25), supplementary proximate data (ADS 31_0), or left blank (ADS 24). The rules for which one to employ are provided in the next section.

Any proximity encounter can be joined with the own data in the first case, but the supplementary proximate data in the second case must be that of the most critical encounter. With this stipulation, the onboard avionics will know which position data set to join with this supplementary data. As a result of this rule, though, the own plus supplementary message can never be employed when a threat exists, as then no proximity encounter will be most critical.

4.2.3 Proximity Messages (ADS 25, 26_0, 26_1, 27, 28)

Every proximity encounter is begun with a start proximity message (ADS 26_0) so that sophisticated users will receive the data required for initiating an encounter file. This message also includes the position data for this first scan. Then, once the encounter geometry no longer exists, an end encounter message (ADS 26_1) is transmitted so that sophisticated users will know to terminate the file. The position data in this message is identical to that sent the previous scan, so that positional correlation can be performed when multiple encounters with the same track number exist (as can be caused by multiple sensor uplink scenarios).

After the initial scan, a position data set is transmitted once per scan for a proximity encounter. If multiple proximities exist on any scan, two such sets at a time are sent via dual proximity messages (ADS 27). If only one proximity exists, or if one is left after the dual messages, it is sent as

either an own plus proximity message (ADS 25) or a single proximity message (ADS 28). The former message is employed if an own data set is required on the scan, the latter otherwise. Thus, the supplementary proximate data, which is the other half of the single proximity message, is transmitted only when no other data set is required and 24 bits are unused. Fortunately for sophisticated users, this will be the normal case when only one proximity encounter exists for the subject aircraft. Unsophisticated users receiving the single proximity message will simply ignore the second 24 bits. A complete flow chart of proximity message selection rules is provided in the next section.

4.2.4 Threat Messages (ADS 26_1, 29, 30)

A threat message (ADS 30), consisting of a position and a basic threat data set, is transmitted every scan on which a threat encounter exists. In addition, a start threat message (ADS 29), containing start and own data sets, may be required on the initial scan of a threat. This message is always required if the encounter begins in the threat state, but is only required for an encounter transitioning from a proximity to a threat if it supplies updated information required by onboard avionics for coasting or closest point of approach calculations. That is, it is sent if:

1. an own data set were required in any event on that scan for a reason given in 4.2.2

2. the last reported velocity for the encounter (via a proximity start or supplementary proximate data set) is no longer accurate in either a percentage or absolute sense.

Finally, if a threat encounter ends, without reverting to a proximity, an end encounter message (ADS 26_1) is sent. Its format is as described in the previous section.

4.2.5 Resolution Message (ADS 31_1)

The resolution message is transmitted once each scan to an aircraft as long as one or more resolution advisory exists for it. In addition, one final null resolution message is sent when the last resolution advisory has been terminated so the onboard avionics will know to cancel its resolution display; otherwise it would have to wait until a resolution timeout period expired.

This message is temporary, to be employed only until the RAR is operational. Thus, no second data set has been defined for the second 24 bits. Instead, they are all set to zero except for the final one; this permits the resolution message (ADS 31_1) to be differentiated from the own plus supplementary message (ADS 31_0).

Since this message is temporary, no provision has been made for multisite resolution logic. That is, each resolution message is taken to present the entire active set of resolution advisories. Thus, if such messages are sent from two or more sites, each message must include the resolution advisories being issued by the other sites or it will cause those resolution advisories to be erased.

4.3 Message Transmission Rules

The previous section has listed the various ATARS messages available for transmitting information to the aircraft. In several instances, particularly with respect to own and proximity data, choices of message exist. This section will describe how encounter status, information already available on board, and presence of other encounters define the rules for message selection. Figure 16 provides the overall flowchart for this selection process.

Besides specifying which messages to employ on a scan, this flowchart also defines the order in which the ATARS messages are to be transmitted. Ordering is important because of the DABS Comm-A message protocol for the data link. In particular, ATARS messages that fail to be transmitted due to infrequent lack of link time will be discarded.

Two classes of data link messages are defined by DABS: priority and non-priority. Messages of the former class are always transmitted before those of the latter class. Within each class, messages are transmitted by a first-in-first-out protocol. Thus it is the responsibility of ATARS to list its messages in order of importance.

Referring to the flowchart, it is seen that the two priority messages, resolution and threat, are put at the head of the list whenever required. The resolution message, presenting the resolution advisory or set of advisories, is the most important. It is used during a serious threat situation, and also on the first scan after encounter resolution to terminate the advisories. One threat message is required per threat encounter existing for the scan. These messages are ordered as described in Section 2.2.

If a threat encounter starts in that state, a start threat message is required on the first scan in addition to the threat message. However, if the encounter has transitioned from proximity to threat status, this message may or may not be required; Section 4.2.4 described the criteria for this choice. Since the threat start message is non-priority, it might not be transmitted due to the presence of too many priority messages. In that event, it must be re-formatted and placed on the ATARS list on the next scan until transmitted to and acknowledged by the aircraft.

After all threat encounters have been considered, the messages for the proximity encounters (if any) are created and placed on the list. The second page of the flowchart details the applicable logic. First the newly begun proximity encounters are handled in order of rank, with a start proximity

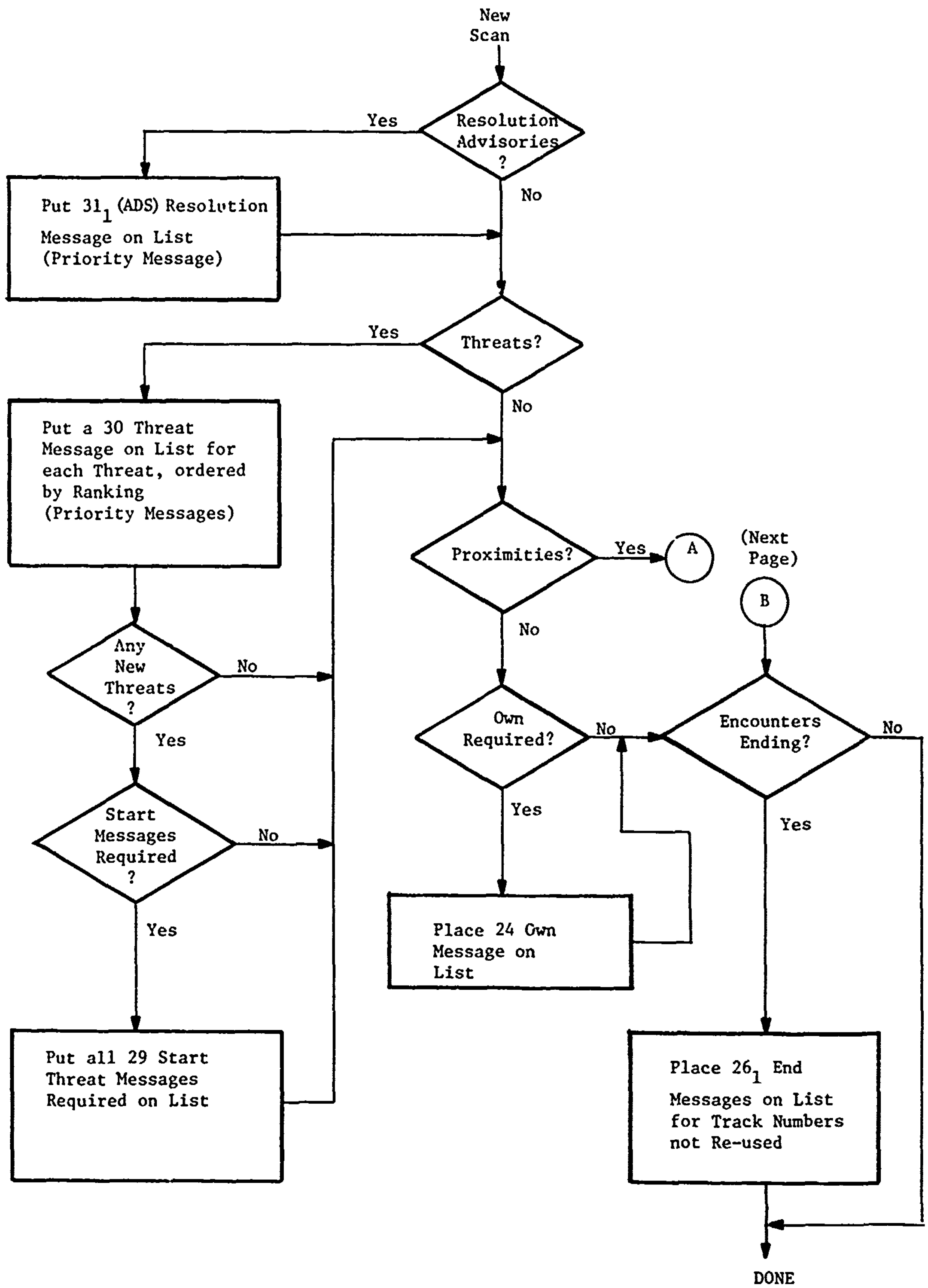


Fig. 16. Ordering of ATARS Messages (1 of 2).

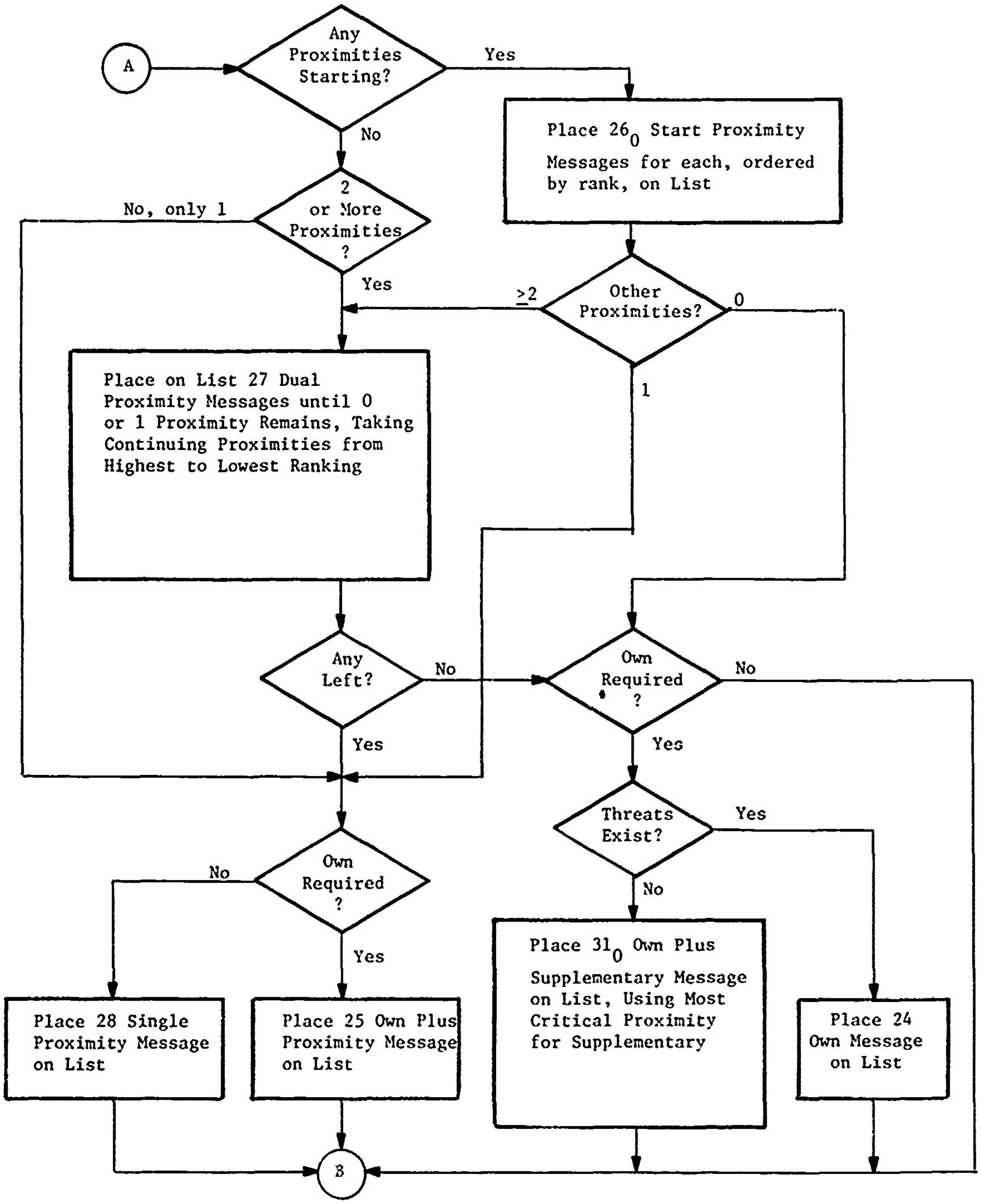


Fig. 16. Ordering of ATARS Messages (2 of 2).

message created for each. As with start threat messages, the start proximity messages must be re-created each scan until successfully received by the aircraft. Then the proximity encounters continuing from previous scans are processed.

The main message for presenting proximity encounter position data is the dual proximity, which provides that data for two separate encounters. As long as two or more proximity encounters remain to be processed, the highest ranking two of them, as defined in Section 2.2, are used to construct such a message. Should only one proximity encounter remain, its data is placed into either an own plus proximity message or a single proximity message. The former message is employed whenever own data is required on the scan for a reason described in Section 4.2.2. If that data is not required, or has already been sent via a start threat message, a single proximity message is used in which the remaining 24 message bits are used to transmit supplementary proximate data for the encounter. Thus this added data is only sent for the least important proximity. However, since proximity rankings will vary from scan to scan, the data should periodically appear for all encounters.

If all proximity position data is handled by dual proximity messages, and own data is required on the scan, one of two message types may be applicable. If no threat encounters exist, the own plus supplementary message is employed, with the supplementary data being that of the proximity encounter labelled most critical. Otherwise, if a threat exists and hence no proximity can be most critical, a simple own message is employed. Also, if only threat encounters exist, with no proximity, the simple own message is used for own data when required.

Finally, if an encounter has terminated on the current scan, an end message is created for it. This message is cancelled, however, if that encounter track number has already been assigned to another active encounter as discussed in Section 4.1.4.

4.4 Alternative Messages not Selected for Implementation

This section describes modifications and additions to the ATARS message set described in section 4.2 that might prove useful in future ATARS systems. None of these features are currently under consideration.

4.4.1 Aircraft Information Messages

At present, there are 13 bits reserved in the start threat and start proximity messages for aircraft identification data. These data fields have been left undefined for now as no such information is available in the ground sensor. However, once such information is provided, it may well require more than 13 bits for its presentation.

A complete aircraft specification could include the airline or operator of the encounter aircraft (such as Eastern Airlines), its flight number (such as 137), and the type of aircraft (such as jumbo or light twin). This description would help the pilot visually acquire the aircraft and allow him to listen to ATC voice messages sent to it. Although the DABS sensor does not contain these items of information, a combination of DABS transponder flight number readout and access to flight plan data over the existing DABS-ATC ground link could easily provide them.

Any three digit flight number could be represented by a 10 bit field (2^{10} = 1024). There are two contrasting methods for representing the airline and type data, however. The one requiring the fewest bits is table lookup. With this scheme, all airlines and operators are assigned a number (such as 1 = Eastern Airlines, 2 = Wiggins Airways, etc.), as are all possible types of aircraft. Then, for example, if 7 bits and 4 bits, respectively, are used for the data fields, 128 airlines or operators and 16 types of aircraft could be represented. The onboard computer would have the two decoding tables in its memory, and would thus be able to read the field values and provide the display with the proper character strings (EA, JUMBO, etc).

The main drawback of this scheme is the difficulty caused by growth. Each time a new airline or aircraft type was required to be added to the system, a new lookup table would have to be constructed. Then every aircraft that wanted to stay current would require an avionics upgrade.

A more direct approach, but one that requires more bits to implement, is the straightforward encoding of the character strings themselves. Any letter can be denoted by a 5 bit number: A=1, B=2, ..., Z=26. Thus, if every airline or operator could be identified by being assigned a two letter code (EA=Eastern Airlines), and every type of aircraft was readably abbreviated by three letters (JMB=jumbo, LTW=light twin), 10 bit and 15 bit message fields respectively would be required. The onboard computer in this scheme would simply read the character string and present it for display. Growth would be transparent to the avionics, as new character strings would be read as easily as old ones.

With this approach, the three aircraft information fields would require a total of 35 bits. Figure 17 illustrates how a new start threat message could be formatted to accommodate these lengths. Since the own data no longer appears in this message, it would require another message for its transmission. However, new own data is often not required when a threat encounter begins. Also, extra bits for its transmission may already exist, such as in an own plus proximity form. Thus, few additional own messages should be produced as a result of this message change.

A proximity encounter would probably not require as full an aircraft specification. If only the most important field were sent, namely the aircraft type, the proximity start data set depicted in Figure 18 would suffice. The loss of the start/end differentiation bit (see Figure 11) could be overcome by using different ADS values for start and end messages, while the coarser

Field	Bits	Interpretation
Continuation	1	(1) Track Number Exists from Previous Proximity State (0) New Encounter
Velocity	7	10 knot lsb
Track Number	3	0 through 7
Aircraft Type	15	3 letters, 5 bits each
Airline/Operator	10	2 letters, 5 bits each
Flight Number	10	3 digit integer
Spare	2	-
TOTAL	48	

Fig. 17. Revised Start Threat Message.

Field	Bits	Interpretation
Velocity	6	20 knot lsb
Track Number	3	0 through 7
Aircraft Type	15	3 letters, 5 bits each
TOTAL	24	

Fig. 18. Revised Start Proximity Data Set.

velocity value resulting from the loss of one bit in its field would still probably prove adequate. Since the proposed threat start message contains aircraft information not present in this proximity start set, it would now have to be transmitted every time a proximity encounter transitioned to a threat.

If longer airline flight ID's are introduced, such as three letter and 4 number designations, the proposed fields would no longer suffice. In that case, a separate message for aircraft information would be required.

4.4.2 Supplementary Threat Message

Chapter 3 has discussed the possibility of providing more complete threat encounter data to sophisticated users if different classes of ATARS users are defined. Also, a complete closest point of approach (CPA) specification may be required for all users if the calculations presented in the Appendix prove to provide unworkable results due to the quality and accuracy of the available uplinked data. Thus, Figure 19 is provided to suggest a possible supplementary threat message that would serve either function.

The first field provides the threat velocity data that is missing from the basic threat message. Then the next five fields supply the closest point of approach time and location quantities that presently require onboard calculation. The track number, also present in the basic threat message, permits a means to correlate basic and supplementary threat messages for an encounter whenever two or more threats exist. Finally, the own heading and own velocity fields have been placed in the available remaining message bits to eliminate the need for separate own messages during the time a threat encounter exists.

4.4.3 Generalized End/Handoff Data Set

The currently defined end encounter message (refer to Figures 11 and 15) wastes a large number of bits. First, only the 3 bit track number is used in the End Encounter Data Set; second, a full Position Data Set is not required for onboard correlation when the identity of the encounter being terminated is in doubt. Thus, this entire message can be reduced well below the 24 bit data set size.

The present thinking concerning handoffs of threat encounters is that both the old and the new sensor will employ the same track number, and thus no onboard notification of handoff actions is required. However, when site identification bits are added to the ATARS COMM-A messages, a sophisticated user will be able to detect the change of sensor for the track number being handed off. He will then not be certain whether a handoff has actually occurred, or whether the second sensor is independently reporting on a separate encounter and coincidentally using that same track number. As stated earlier, various unusual or error conditions can result in such multiple sensor reporting of encounters.

Field	Bits	Interpretation
Velocity	7	10 knot lsb
Time to CPA	6	1 second lsb
Altitude Zone at CPA	2	see Fig. 9
Relative Altitude at CPA	3	see Fig. 9
Clock Bearing at CPA	4	see Fig. 9
Fine Bearing at CPA	3	see Fig. 9
Track Number	3	0 through 7
Own Heading	7	see Fig. 8
Own Speed	7	see Fig. 8
Spare	6	-
TOTAL	48	

Fig. 19. Possible Supplementary Threat Message.

To prevent such confusion, use of a handoff message is proposed. As illustrated in Figure 20, a combined End/Handoff Data Set has been defined; the first bit differentiates handoff from end situations. In the former case, the new sensor's track number and that of the previous sensor are provided. Allowing this number to differ may be necessary if future more complex handoff protocols are introduced. A velocity field is also provided in the not unlikely event the new sensor's tracker has determined a different value from that of the old tracker.

Used to end an encounter, the track number field specifies the one being terminated. In case of doubt caused by multiple track number use, the few position fields provided are more than sufficient to choose the applicable encounter through correlation. The new position set format is acceptable as only sophisticated users will be interested in the message. Finally, the last bit permits an end message to be transmitted even when the track number is already being reused for a new encounter. This simplifies the onboard logic. Since this new end message is only 24 bits, two per COMM-A, or one with an own message or position message, is possible.

Handoff:

Field	Bits	Interpretation
Termination	1	Set to 0
New Track Number	3	0 through 7, new sensor
Old Track Number	3	0 through 7, previous sensor
Velocity	7	10 knot lsb
Spare	10	-
TOTAL	24	

End Encounter:

Field	Bits	Interpretation
Termination	1	Set to 1
Track Number	3	0 through 7
Clock Bearing	4	see Fig. 9
Fine Bearing	3	see Fig. 9
Altitude Zone	2	see Fig. 9
Relative Altitude	3	see Fig. 9
Range	6	see Fig. 9
Track Reuse	1	(1) Track Number Being Reused (0) Track Number Terminated
Spare	1	-
TOTAL	24	

Fig. 20. Proposed End/Handoff Data Set.

5.0 ALTERNATIVE SYSTEMS

As might be expected, the system described here is not the only method that could be proposed for delivering information about other aircraft to pilots. In particular, three decisions that were made were to:

1. display only aircraft that are threats or potential threats, rather than all aircraft in the vicinity as in a CDTI system

2. perform tracking on the ground rather than in the aircraft

3. use relative rather than absolute bearings and altitudes

In each case, as explained below, onboard hardware simplicity and pilot display clarity were factors in the decision.

It might appear that the ATARS traffic advisory service is a subset of CDTI, and would not be required if the latter were implemented. However, the desire to provide altitude, heading, and velocity of threat aircraft to aid in pilot acquisition and avoidance negates this assumption. It would be impractical, in any display that could fit in a cockpit, to provide this level of data on any sizeable number of aircraft. Also, by providing data only when potential threats exist, pilots can more easily notice and utilize the data. Thus, CDTI should be viewed as a companion, rather than competing, service to ATARS.

The ATARS traffic advisory service, as viewed herein, sends traffic advisory messages directly addressed to each aircraft for each advisory. An alternative approach would be to use a broadcast mode of data link messages. In this mode, a position message for each aircraft would be broadcast to all listeners once per scan. The onboard equipment would then filter these messages to locate all potential threats, track the relevant aircraft via the periodic position reports, and provide its own traffic advisory service. The major drawback of such an approach is the sophistication level of onboard equipment that it assumes. In addition, the character of the sensor surveillance error ellipse is such that an onboard tracker could not possibly be as accurate as a ground-based one. Also the ground tracker would have an established track at the time the encounter began, while the onboard one would require several scans for initialization, thereby delaying accurate display presentation. Finally, the presumed advantage of the broadcast mode, fewer uplink messages, is largely illusory. Almost all of the time, 2 or fewer advisories will exist for an aircraft, and often both of these can be included in the single "free" COMM-A that is part of a DABS surveillance request.

The main reason for selecting relative bearing of a threat aircraft for display is the belief that pilots would find it easier to visually acquire an aircraft with that data format. The main drawback of this approach is that the relative bearing might contain a bias caused by the ground tracker error of the subject aircraft's true heading. This can be corrected onboard by tying the aircraft instruments into ATARS avionics.

Although ARINC studies [6] have shown that pilots prefer absolute altitude on their display, relative altitude was chosen for ATARS messages because this format requires many fewer bits to specify and permits simpler onboard displays. Users may display absolute altitude by making encoded altitude and altimeter correction available to the ATARS display. This makes it possible to determine corrected own altitude which when added to the relative altitude in the ATARS messages gives the absolute altitude of the threat and proximate aircraft

6.0 ATARS AVIONICS

The messages which have been described are capable of supporting a wide range of onboard equipment. In general, two pieces of hardware are required: a processor to decode the messages, and a display to present the proximity, threat, and resolution data to the pilot. The processor can be as simple as a few hardwired chips of logic or as complex as a full-scale microcomputer system, while the display can vary from a set of lights or synthesized voice, to an alphanumeric display, all the way to a complete graphics system.

This chapter describes some examples of both unsophisticated and sophisticated onboard display systems to indicate the types of implementations that can be supported by the previously defined messages. The basic means of differentiating between the two user classes is that unsophisticated users make no use of encounter track numbers, while sophisticated users maintain onboard track files for the active encounters. Thus, only the latter user attempts message-to-message or scan-to-scan correlation.

Of course, numerous other displays than those presented here, for both sophisticated and unsophisticated users, could be designed. In addition, numerous variations or combinations of these systems are possible. Also, joint displays that integrate ATARS with other aircraft functions may be desirable. The intent of this chapter is to provide representative examples over a wide spectrum. Some of the factors expected to influence actual implementations are cost, avionics technology, cockpit space, and usefulness of the various pieces of uplinked information.

6.1 Common Avionics Requirements

Several onboard avionics requirements are common to all display systems, from the simplest unsophisticated one to the complete graphics system. First, any ATARS message may be repeated several times by the ground if proper downlink acknowledgment is not received. Thus, a duplicate message removal capability is required. Conversely, any ATARS message prepared by the ground may not be transmitted if data link time is not available. Thus, provisions for holding or coasting an advisory are required to bridge scans with missing position reports. Also, timeout hardware is required to remove outdated encounter or resolution information as end messages may be missed. Current thinking is that encounters should be coasted one scan and then dropped if not updated, while resolution advisories should be held for 16 seconds.

All avionics processors must be able to recognize the various message ADS codes so as to be able to find the data they need. However, not all data sets must be read. For the simplest display, only the Position and Resolution Data Sets are required. Thus, fairly simple processors may be possible in the

ATARS avionics. However, as microcomputer costs continue to drop, it may well be feasible to provide the same processing unit for any display, and "plugging in" of different display units could be achievable. Then "low cost" or "high cost" would refer only to the display technology and complexity being utilized.

6.2 Unsophisticated Displays

An example of a simple display is an upgraded IPC display, as depicted in Figure 21. The IPC studies have shown that range, altitude, and heading of the threat aircraft are necessary for rapid pilot acquisition and threat assessments techniques. Thus, these quantities have been added for the most critical encounter as numeric fields in the center of the display. Also, the control and ATARS status of the other aircraft are noted for pilot information.

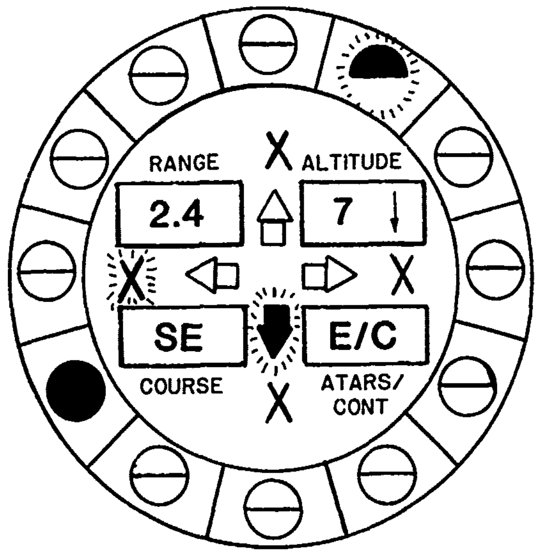
The Position Data Set, which is provided for every encounter, proximity or threat, has fields for bearing clock position and relative altitude zone. Thus simple direct connections to the light circuitry could be made. If several advisories existed at the same time, a light for each, non-flashing or flashing according to its proximity or threat status, would be lit. The resolution display area would be activated whenever a resolution message were received, and cancelled upon reception of the null resolution message, or by a timeout.

The data for the inner numeric fields would be copied from the corresponding message fields every time a Position Data Set with its most critical flag set were received. This data could continually update one encounter, or change from one to another, according to changing threat situations. The light corresponding to the current most critical encounter would be special in some manner (color, shape, etc.) so that pilot correlation would be possible. If no message were received for several scans, the data would be timed out.

This avionics would only need the ability to decode the Position and Resolution Data Sets to obtain all its information. A slightly more complete threat encounter representation, displaying an up/down arrow for vertical maneuver and a numeric miss distance field, would also require decoding of the Basic Threat Data Set.

A simple synthesized voice system can also be constructed to present ATARS advisories. Some level of hardware complexity is required for message filtering, as voice channel time considerations prevent even the most critical encounter from being described more often than every few scans. A set of sample rules for selecting an advisory might be as follows:

1. always present the new resolution advisory as soon as possible after reception of a resolution message with the first time transmitted bit set (unless a special display exists for resolution advisories)



Situation:

Threat above at 1 o'clock (flashing)
Proximity co-alt at 8 o'clock (non-flashing)

Resolution:

Descend, don't turn left

Fig. 21. Upgraded IPC Display

2. insure that the most critical message information is presented every n scans (n a parameter)

3. present a voice report whenever a new threat encounter begins, as signalled by a threat message with its first time transmitted bit set

4. time permitting, present a voice report each time a start proximity message is received

5. with the remaining time on the voice channel, periodically describe the non-most critical encounters to the extent permitted by the hardware complexity.

This avionics would also require a repeat button to prevent the pilot from missing advisories blocked by radio communications.

Another system that might be employed for an unsophisticated user is the <u>multiple encounter alphanumeric display</u> illustrated in Figure 22. As shown, the display can support two encounters; other numbers of lines could obviously be provided. One of the encounters shown on the display will be the one flagged as most critical, while the other could either be selected at random to provide rotating coverage or be the second one received which, by the transmission rules presented above, will be the second most important. In the former case, though, threat situations must be given priority over proximities. Any resolution messages received are displayed on the bottom line.

The final example of an unsophisticated user display to be considered here is the <u>3" CRT</u> currently under development at Lincoln. A sample screen picture is shown in Figure 23. All encounters located within the screen's range are displayed in the manner suggested by the figure: proximities with position and relative altitude zone indications, threats with current position, numeric relative altitude, and 60 second relative motion projection. The resolution advisories are displayed in two screen areas simultaneously for emphasis and clarity.

In order to maintain a constant scale on this small display screen, a fixed display cutoff must be chosen for the advisories. A reasonable limit is 4 miles, as this distance satisfies three key criteria:

1. most advisories, for most aircraft, fall within this limit

2. it is unlikely that a pilot could visually acquire an aircraft further away than this distance

3. a larger limit would compress the screen so much that pilot readability for critical close-in encounters would be compromised.

TRAFFIC ADVISORIES					
TYPE	BEARING (O'CLOCK)	ALT (100 FT)	RANGE (N MI)	COURSE	STATUS
THT	10	+06	2.8	SE	E/C
PROX	3	-02	5.1	N	U/N

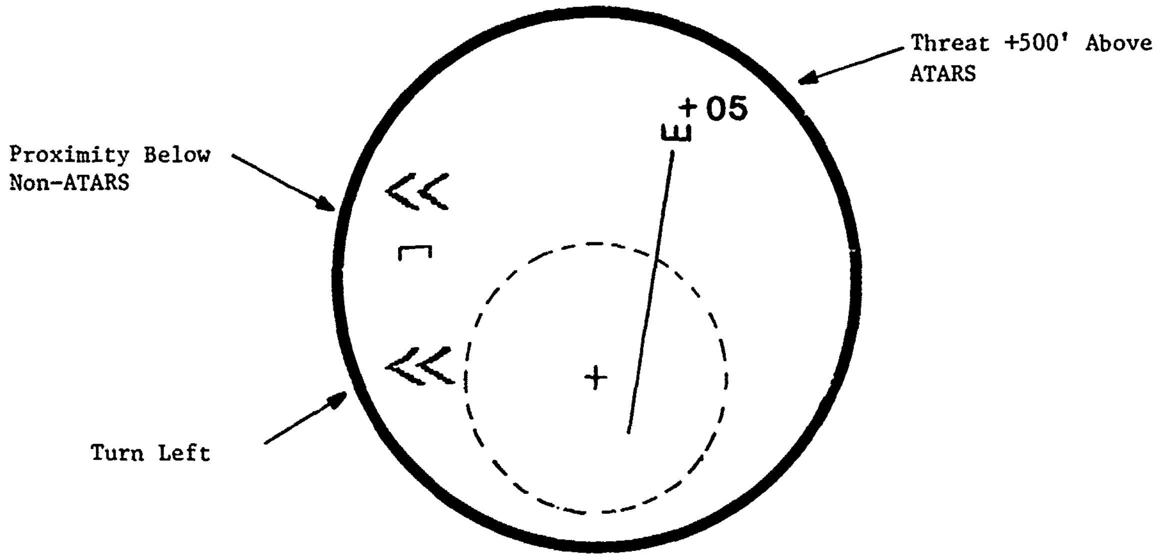
RESOLUTION ADVISORY

CLIMB TURN RIGHT

Status:

ATARS: Equipped (E) or Unequipped (U)
Rules: Controlled (C) or Not Controlled (N)

Fig. 22. Multiple Encounter Alphanumeric Display



Arrowhead symbols and threat position symbol would be flashing.

Fig. 23. Sample 3" CRT Display.

It should be emphasized, though, that this limit could be a user parameter, as advisory messages are transmitted for all encounters, regardless of range.

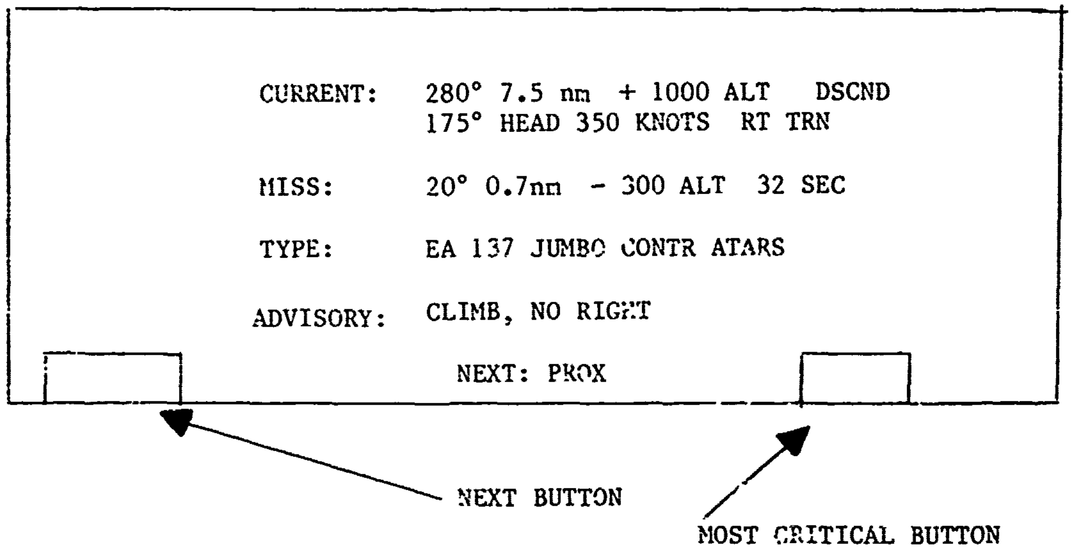
This display, although still unsophisticated, does require a considerable level of computational power. In particular, the calculations required for the relative motion vector and resolution positioning features are relatively complex.

6.3 Sophisticated Displays

As the first example of a sophisticated user display, consider the single encounter alphanumeric display depicted in Figure 24. With this display, complete information is presented for the most critical encounter. If other encounters exist, the type of the next most critical is shown beside the next button. By pushing this button, the pilot can see the data for that encounter. By successive pushes, all situations can be viewed. A separate button provides for immediate return to the most critical encounter.

Track numbers must be employed in this system for two reasons. First, it is the only method that could be used to correlate start, proximity, and threat messages so as to gather together and compute all the data displayed for an encounter. Second, it is needed to insure that any given encounter stays on the same display "page", so that a pilot will not experience flicker.

Finally, the full graphics system, which has been developed as part of the Lincoln ATARS program, is described in detail in the remainder of this document.



Shows Most Critical Encounter (A Threat)

Next Most Critical Is Proximity

Fig. 24. Single Encounter Alphanumeric Display

7.0 LINCOLN ATARS GRAPHICS DISPLAY

The graphics display developed by Lincoln Laboratory for ATARS testing is a subset of the CRT system being implemented as part of the DABS Data Link program [3]. As shown in Figure 25, it is based upon a Bendix color radar CRT. The screen can be filled with 13 lines of 32 characters each, or can have various graphic symbols, such as lines and arrows, placed at any position. In addition, several different colors can be used for the display. The input keyboard can be used to enter commands, respond to screen questions, or control the display.

In operation, the display will be time-shared between the ATARS, Data Link, and weather radar functions, with relative priorities and pilot input determining the usage at any instant of time. In general, whenever a threat situation exists, ATARS will be in control of the display.

This chapter and the two remaining will describe the overall system, user interaction, and software implementation respectively of this graphic display. A fairly complete level of implementation detail will be provided in each case. This is not being done under the expectation that avionics manufacturers will copy the Lincoln system, as it was never intended to serve as a prototype. Rather, the intent of this discussion is to present the many complex and unusual considerations that must be addressed by such manufacturers when developing a display that will function properly under both normal and extraordinary operation of the ATARS ground system.

7.1 Graphic Display Format

The proposed size and shape for the nominal ATARS graphical display region is computed by assuming the relative aircraft headings and velocities in a threat encounter are "optimal" to produce the minimum time to collision. Assuming a maximum speed of 360 knots, the equation for the 50 second boundary is:

$$\rho = \begin{cases} 10 \cos \theta & 0 \leq \theta \leq 45° \\ 5/\sin \theta & 45° \leq \theta \leq 90° \\ 5 & 90° < \theta < 180° \end{cases}$$

where ρ is the distance between the aircraft and θ is the bearing of the other aircraft relative to the heading of the subject aircraft. The first two relations are exact, while the last is a simple approximation to a complex term. Figure 26 illustrates the shape of this display region, which is two semicircles connected by a fixed width segment. Proximity or threat aircraft located outside this boundary will still be reported, and will be displayed as explained below.

The screen format when ATARS is being displayed is shown by Figure 27. Whenever possible, the top 3 lines are reserved for critical tactical Data Link messages. Thus these messages need not be delayed, nor would they have to displace ATARS. The center of the screen, with dimensions matching the threat

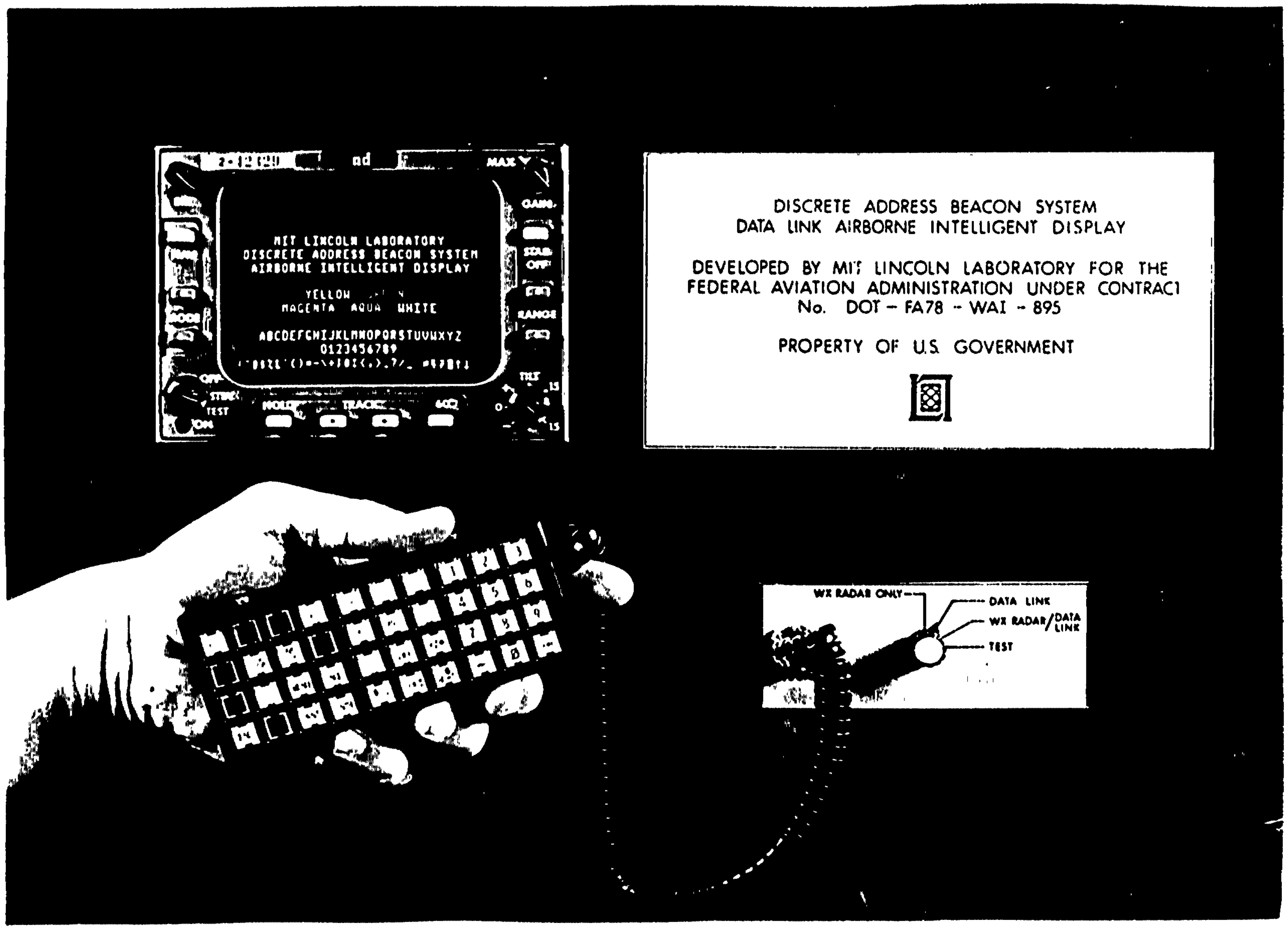


FIG. 25. AID DISPLAY AND KEYBOARD

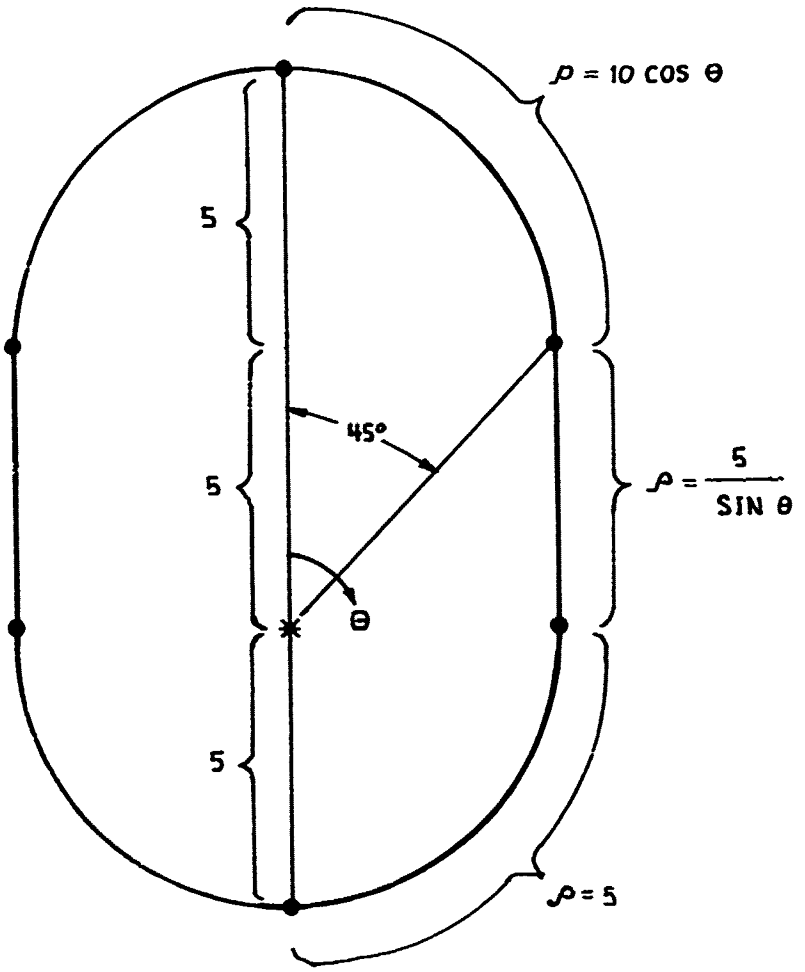


Fig. 26. Threat Area Geometry

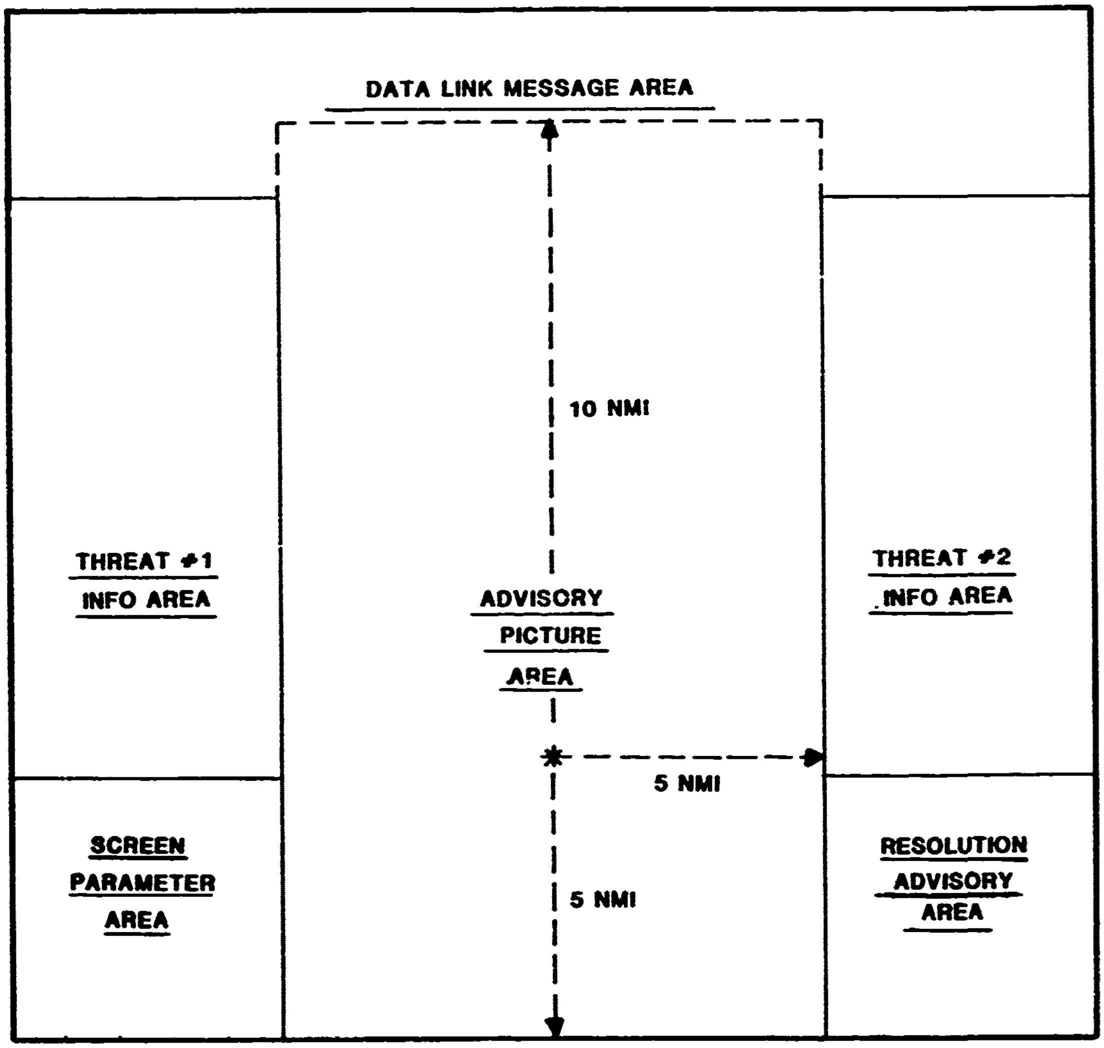


Fig. 27. ATARS Screen Format

region just calculated, is used to show the current locations of all encounter aircraft and the projected closest approach positions of all threats. Whenever a threat aircraft is located within the dotted region shown in the figure, the Data Link area is reduced to a single line. This single line is still sufficient for tactical messages provided they are abbreviated. Finally, the side panels present additional alphanumeric information for threat situations. Each such encounter requires one side; thus, the additional data for at most two threats can be accommodated at one time. If an active resolution advisory exists, it is presented in red at the lower right of the display. The lower left corner posts the current display format parameters in effect (defined in section 8.2).

A sample maximum format ATARS display, shown in color and illustrating the proposed methods for presenting the data for aircraft involved in encounters with the subject aircraft, is given by Figure 28. Threat aircraft information is drawn in white, proximity information in green. The current relative position of either type of encounter aircraft is marked by a plus sign at the proper range and bearing. This symbol may have any or all of four diagonal lines added to indicate the following status situations:

- aircraft is ATARS equipped
- aircraft is controlled
- aircraft is a threat
- aircraft is receiving ATARS resolution advisories

Above the symbol, the relative altitude of the encounter aircraft is indicated by a signed alphanumeric label, such as +05 for 500 feet above. Threat encounters may in addition have a vertical arrow following the alphanumerics to indicate direction of vertical speed, if any. Originating at the position symbol is an arrow whose direction and length represent the relative heading and speed of the encounter aircraft. The length presents the distance to be traversed by the aircraft in the next 10 seconds, except that minimum and maximum lengths are enforced. In addition, the end of this arrow will be tilted right or left for threat encounters if the aircraft is executing a turn.

Threat encounter representations also include a relative motion display component. This representation includes the following features:

1. an X marking the predicted closest point of approach of the threat aircraft, labelled with the expected relative altitude at that time

2. a relative motion line, with ten-second tick marks, connecting the current position symbol for the threat with that X

3. a leader line to the side of the display on which the time to closest approach and aircraft information for the threat are listed.

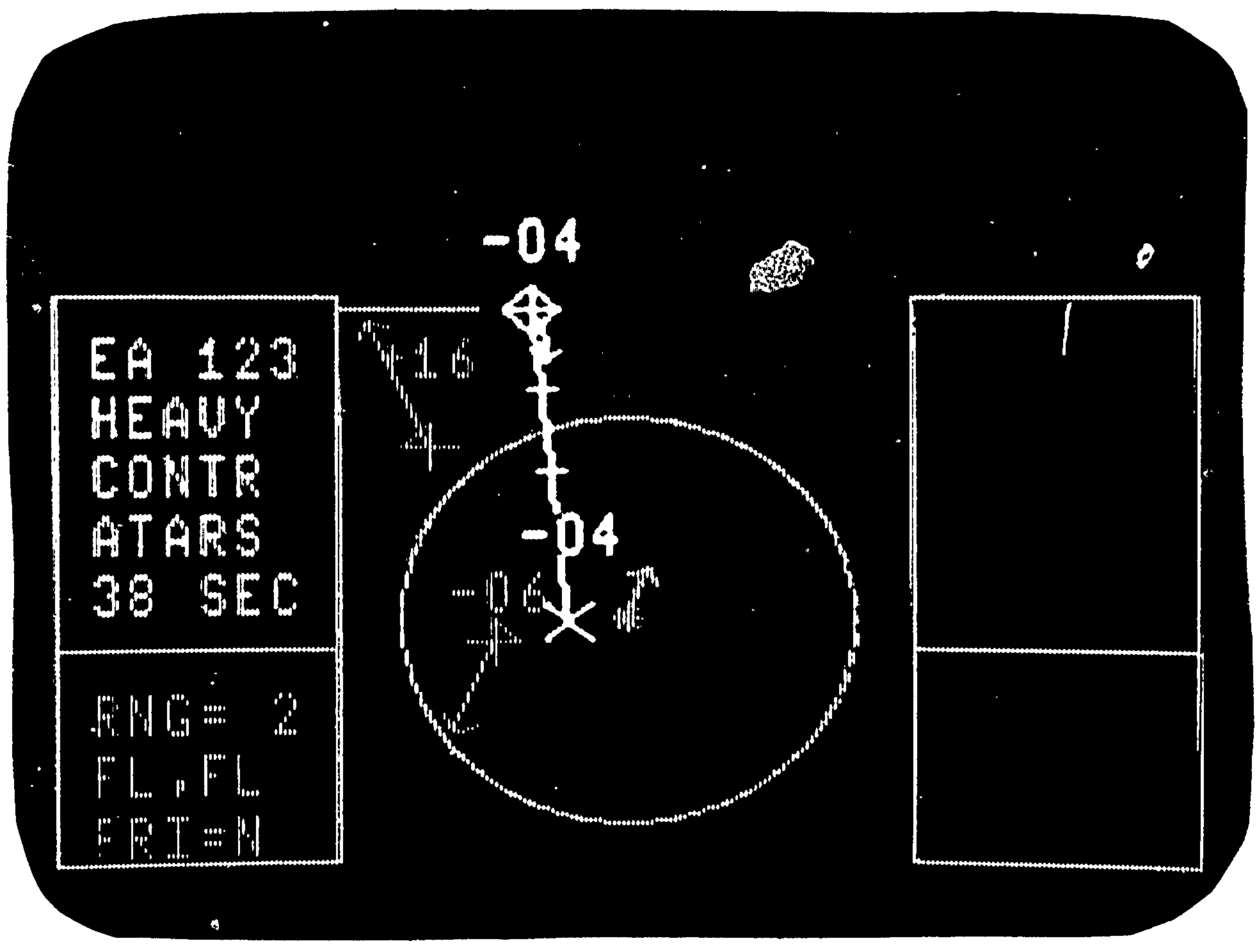


FIG. 28. SAMPLE ATARS DISPLAY

If any encounter is out-of-range for the display area dimensions, it is represented by a triangle on the perimeter at the proper current relative bearing. No alphanumeric information is included in this case. However, if the encounter is a threat, the relative motion line segment for the display area is included, as is the closest point of approach information. The tick lines are deleted, though, as they would be meaningless in this format.

In addition, the display has two fixed features. First is an asterisk for the subject aircraft with an arrow whose length and tilt represent its speed and turn status respectively. Second is a two mile range ring that supplies a range reference to the pilot. If the pilot is interested in encounters at greater ranges, or if the current threat situation is such that he wants an expanded screen, he can scale the display to any larger or smaller full range as described in the next chapter.

If the pilot feels that the display format described above is too cluttered, he may select a large range of less complete formats. For example, he may choose a less complete picture for proximity encounters, either a point representation (just the + symbol) or no indication at all. Also, he may greatly reduce the amount of alphanumeric information on the display, such as the aircraft information sidebars. Finally, he may eliminate relative motion and closest approach displays, either for all threats for just for non-most-critical ones. A description of all such options, and the methods to be used by a pilot for requesting them, are presented in the next chapter.

7.2 Microcomputer System

The combined Data Link/ATARS onboard graphic display system employs a Cromemco microcomputer to process uplink messages and prepare the screen display. This computer implements an interrupt driven, multi-tasking system. A schematic block diagram of this system, along with the set of interrupts, is presented by Figure 29. The program flow of the ATARS tasks within this overall structure is shown in Figure 30. All discussion in this section will be in reference to these figures.

In the usual case, this system is activated by the arrival of COMM-A messages at the Standard Message Interface (SMI). These messages must immediately be transferred to a storage buffer, so that the system can be ready to receive the next one. The potential rapid burst rate of COMM-A messages received by the aircraft during the sensor dwell time precludes the system from performing any further message processing until all messages for the scan have been received.

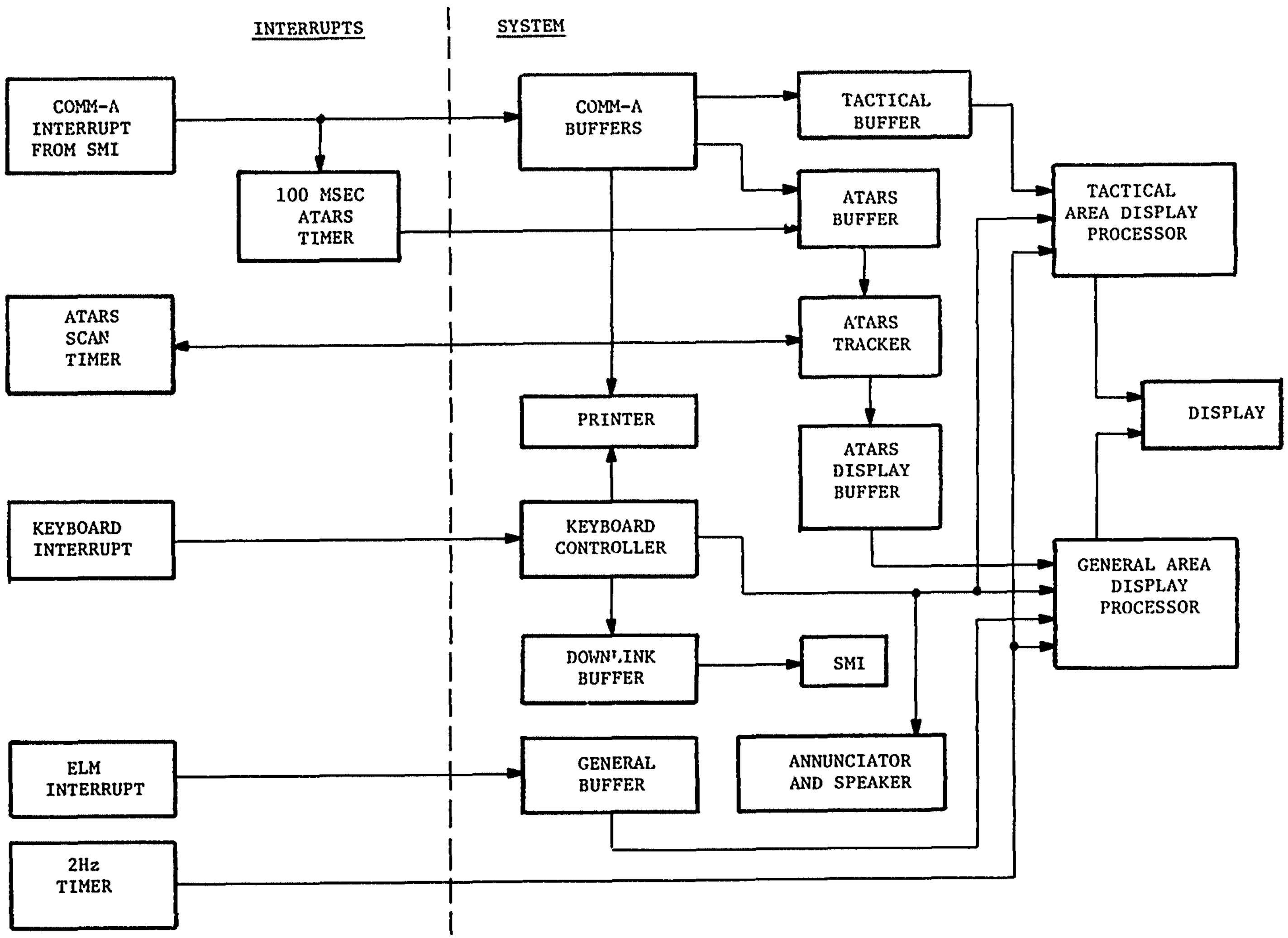


Fig. 29. Data Link/ATARS Computer System.

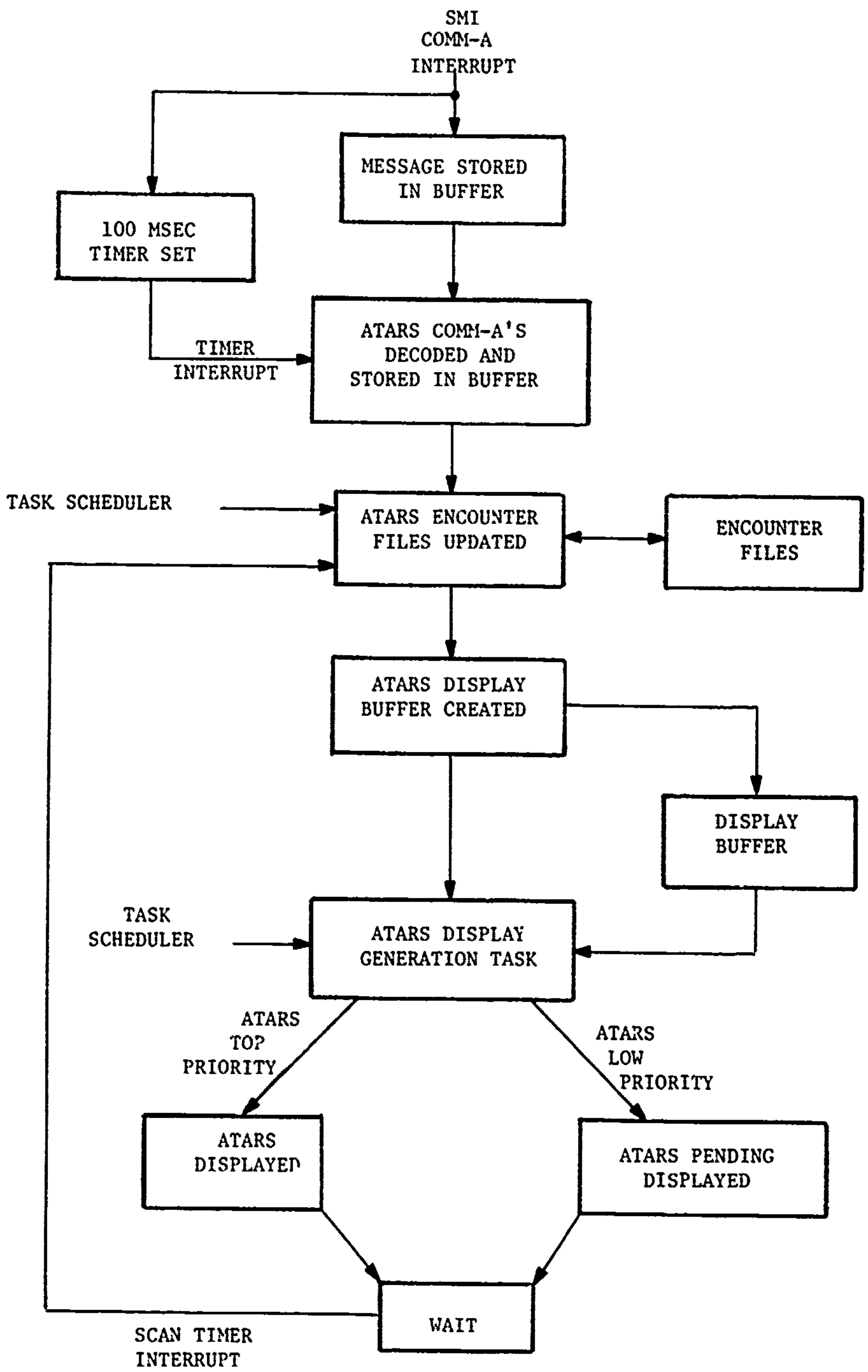


Fig. 30. ATARS Program Flow.

The criterion used to determine when all messages have been received is dead time since the last one. All presently planned sensor antennas will have a dwell time less than 100 milliseconds. Thus, a 100 millisecond timer has been built into the system. Each time a COMM-A arrives, this timer is reset to full scale. When this timer finally counts down to zero, an interrupt is generated that signals the scan completion.

After this interrupt occurs, the COMM-A messages are sorted into separate data link and ATARS buffers. In addition, all of them are printed onboard in case future reference or playback is required. The ATARS messages are decoded during this transfer process, each field being unpacked and placed into a separate word. This new format greatly facilitates downline software processing.

Since the computer is serving many functions in addition to ATARS processing, a task scheduler is needed to arbitrate when several tasks are ready to run. When ATARS processing becomes the highest priority one not yet executed, it is initiated. This processing task has two separate components: encounter file updating (or tracking), and display buffer generation.

The tracking routine is responsible for updating the position and status of every active proximity or threat encounter for the aircraft. Its inputs for these actions are the current scan COMM-A messages and the previously received information as stored in the encounter file. The set of possible actions are the following:

1. update an existing encounter file with the information from a new COMM-A;

2. coast an encounter file for which no COMM-A was received;

3. delete an out-of-date encounter, either through an end message or via timeout;

4. initiate a file for a new encounter.

The routine also maintains current information on the own aircraft and resolution states.

Once the current information on all encounters has been determined, the ATARS display buffer is created. This buffer, whose format is described in the next section, serves as the input for the display generation task.

In addition, a system priority for the ATARS display is also generated. Since the ATARS task must share the screen with data link or weather tasks, a three level (high, normal, low) priority structure has been created to arbitrate screen access. When a task is using the screen, it can be preempted only by a task of a higher priority level. Tasks of the same or lower level

are buffered to await their turn. When the screen becomes free, the highest priority buffered task gains access; among tasks of equal priority, the one waiting longest is chosen. When a task on the screen is preempted by a higher priority one, it is placed first on the waiting list for its priority level.

Thus, the display handler compares the ATARS priority to the priorities of any other entities that are seeking access to the general area of the display. If the ATARS priority is greater than or equal to all others, as well as greater than that of the current display on the CRT, the ATARS display processor is executed. The current display, and others of lower priority, are buffered for future display. On the other hand, if ATARS is lower in priority than other display users, no display is generated, and only an "ATARS PENDING" message is provided. (ATARS displays are never buffered, as a new one is created each scan).

The ATARS display generation task is responsible for translating the display buffer into a format suitable for driving the display hardware. Positioned symbols with associated alphanumerics and character strings for the two side areas are all created to the degree and complexity specified by the display level chosen by the operator. The next two chapters discuss these issues in greater detail.

If tactical data link messages also exist, a separate tactical area display processor is responsible for formatting the top area of the screen to display them. Either one or three lines are available to this processor, depending upon the location of ATARS threats.

Once the display has been generated, the ATARS tasks enter a wait state, awaiting the next scan COMM-A messages. However, if no messages were to arrive, these tasks would not be executed, and the current display would show outdated information. To prevent such an occurrence, a separate scan timer set to 150% of the scan time is activated each time a display is generated. If it times out, an interrupt is generated that produces a new pass through the ATARS tasks. Thus updated displays are produced, including the null one after all encounters have timed out.

The remaining boxes on Figure 29 are for the most part related to the data link system. Every time the user makes a keyboard entry, it is interpreted and the proper action executed. This could be to add to the display text or cause a menu to be displayed, for example. If a downlink message has been generated, it is entered into the downlink buffer and then transferred to the SMI at the proper time. Uplink ELM messages are buffered upon reception, and displayed when the system priorities permit it. Finally, a 2 Hertz timer provides timing interval data required by various tasks.

7.3 ATARS Internal Files and Buffers

The ATARS computer employs several files and buffers to maintain all the historical information considered useful for a maximum format display. This section will present and describe the most important of these data structures. The items contained in each one are important to note, as they indicate the types of information that must be considered by the system designer; the actual formats chosen for the structures are unimportant.

An encounter file, containing the information shown in Figure 31, is maintained for each active proximity or threat encounter. The position quantities, which will always exist, are copied from the most recent position data set. The time of this data set, taken from the system clock, is also recorded to permit coasting during scans on which no message is received.

If the encounter is not brand new (NEW bit = 0 in special bits word), the positional rates are calculated onboard from three successive position messages (only two for the encounter's second scan). Instead of having to store two scans worth of position data to permit these calculations, a single rate direction bit is maintained for each rate field. This bit is set if the rate from the last two data values is larger than the value in the encounter file. This knowledge, plus the next scan's position value, is sufficient for a three scan average. The applicable formulas are:

$$\text{new rate} = \frac{\text{old rate} + \dfrac{\text{new position} - \text{old position}}{\text{scan time}} + \text{rate bit}}{2}$$

$$\text{new rate bit} = 1 \text{ if } \frac{\text{new position} - \text{old position}}{\text{scan time}} > \text{new rate}$$

The velocity, turn type, and vertical speed information will be known for a proximity encounter only if the proper messages types were received: a start for the velocity, supplementary proximate for the others. Thus two special purpose field bits are needed to record the validity of these fields. Note that a zero field value could not be used to indicate unknown values, as zero is in fact a valid number.

If the encounter is a threat, the miss distance field will apply. Also, if the threat is not new, and it satisfies other necessary conditions, the calculations in the Appendix will have been made and the closest point of approach position and time fields will be applicable; the CPA valid bit in the special bits word indicates when this has occurred. The aircraft information fields are reserved for such information as aircraft type, operator, and flight number when the data becomes available to ATARS.

<table>
<tr><td>Track #1</td><td>Track #2</td><td>Track #3</td><td>Track #4</td></tr>
<tr><td colspan="2">Range</td><td colspan="2">Bearing</td></tr>
<tr><td>Alt Zone</td><td>Altitude</td><td colspan="2">Velocity</td></tr>
<tr><td colspan="2">Heading</td><td colspan="2">Last Update Time</td></tr>
<tr><td colspan="2">Miss Distance</td><td colspan="2">CPA Bearing</td></tr>
<tr><td>Alt Zone</td><td>CPA Altitude</td><td colspan="2">Time to Closest Approach</td></tr>
<tr><td>Commanded Bit</td><td>Turn Type</td><td colspan="2">Vertical Speed</td></tr>
<tr><td colspan="2">Range Rate</td><td colspan="2">Bearing Rate</td></tr>
<tr><td colspan="2">Altitude Rate</td><td colspan="2">Aircraft Information</td></tr>
<tr><td colspan="2">Aircraft Information</td><td colspan="2">Aircraft Information</td></tr>
<tr><td colspan="2">Number of Reports</td><td colspan="2">Special Bits*</td></tr>
<tr><td colspan="2">Rate Bits</td><td colspan="2">Aircraft Information</td></tr>
</table>

16 bit words assumed

*Bits for:

Most Critical Encounter	New Encounter
ATARS Equipped	Valid Velocity
Controlled	Valid Turn Type + Vertical Speed
New Threat	Valid CPA Data

Fig. 31 ATARS Encounter File.

The four track number fields in the first word of the file reflect the fact that, in the absence of properly coordinated inter-sensor communications, several sensors can be reporting the same encounter, each using a different track number. Thus, it is not always possible for the encounter file number to agree with the message track number. The translation from message number to file number is handled by the array shown at the top of Figure 32. In each row, indexed by message track number, all encounter files supported by a track of that number are listed. When site ID bits become available to ATARS the confusion of track numbers should be alleviated, as the concatenation of the ID and track number fields would then be unique. However, some error conditions requiring the translation array could still exist.

In addition to encounter files, an own file storing all attributes of the subject aircraft is also maintained. Until the RAR is implemented, this file is also used to store resolution data. Figure 32 presents the fields currently defined for this file. Almost all of the data is copied directly from either the most recent own or resolution data sets. The times of each such data set are also stored, the own time to permit calculation of current heading via the turn rate, and the resolution time to permit timeout determination.

The remaining three own file data items are calculated by the computer. The multi-site count is zeroed every time an own message seam bit is set, and incremented every time it is not. When this count reaches three, single sensor coverage is again assumed by the correlation software. The own acceleration is determined from successive own velocity values, and is used to calculate the current velocity. The largest scan rate is important to know during multiple sensor situations, as the scan timer discussed earlier must be set larger than the period of any sensor uplinking messages. The stored value is updated every time an own data set is received as the weighted average of the old value and the new own data set scan value. This action removes the influence of sensors no longer uplinking messages.

Whenever a new display picture is to be created by the display routine, the tracking routine constructs a display buffer of the form shown in Figure 33 from the information contained in the files just described. The formats for each type of encounter entry are shown by Figure 34. A proximity encounter requires only one such entry, while a threat requires two successive entries for complete definition. The header entry provides buffer processing information, the settings of the display parameters (described in the next chapter), own aircraft information, and the current resolution set. It also has a 3-second bit which, when set, informs the display that less than 3 seconds have elapsed since the last buffer was presented. Many displays should not be updated this quickly for reasons of pilot comprehension.

If an encounter was updated on the current scan, its display buffer information is copied directly from its encounter file. The various validity bits indicate whether the corresponding fields (velocity, turn type and

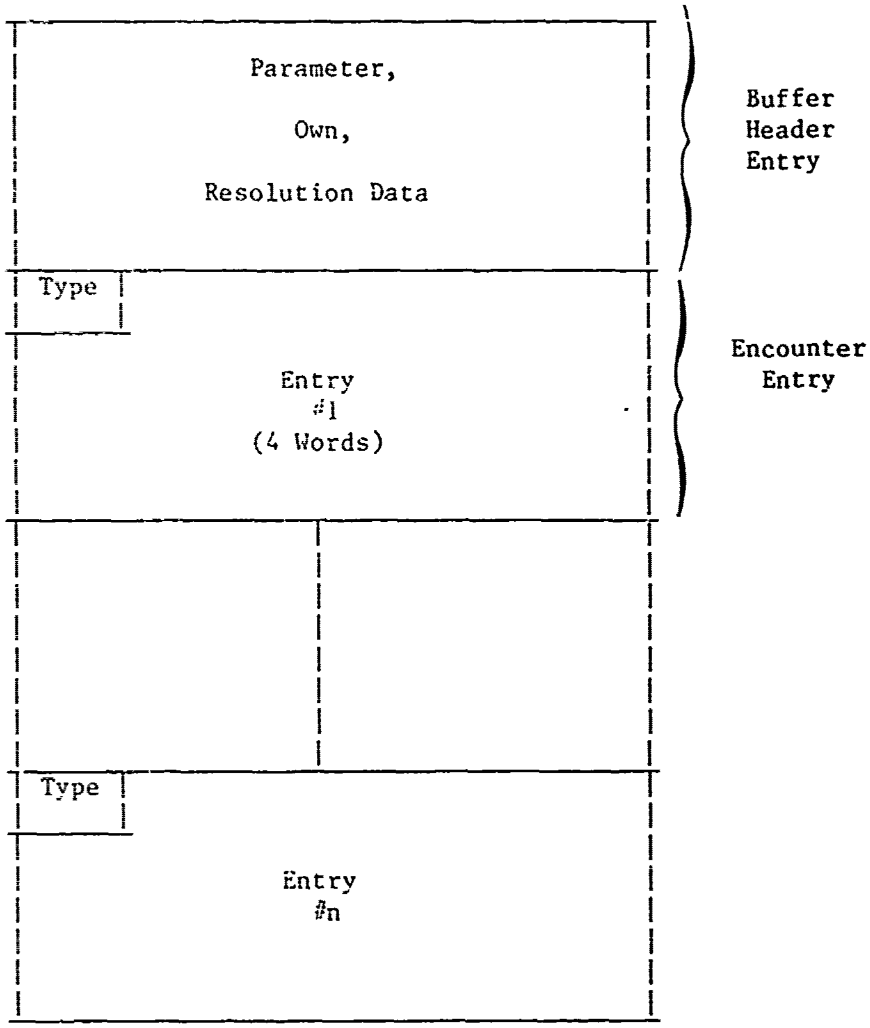
Message Track Number				
0	File #	File #	File #	File #
1				
|	|	|	|	|
7				

Cross Reference File

<table>
<tr><td colspan="2">Heading</td><td colspan="3">Velocity</td></tr>
<tr><td>Turn Rate</td><td>Acceleration</td><td colspan="3">Time of Last Own Msg</td></tr>
<tr><td colspan="2">Positive/Negative Resolutions</td><td>New Res</td><td colspan="2">Vertical Speed Limits</td></tr>
<tr><td colspan="2">Time of Last Resolution Msg</td><td colspan="2">ATARS Level</td><td>Multi-site Count</td></tr>
<tr><td colspan="2">Largest Scan Rate</td><td colspan="3">Last Scan Rate</td></tr>
</table>

Own File

Fig. 32. Auxiliary Encounter Files.



Types:

00 Proximity Data
01 Threat Position Data
10 Auxiliary Threat Data

Fig. 33. ATARS Display Buffer.

# Encounters	# Threats		Prox Mode	Prox Priority
3 Sec	Range Setting		Own Velocity	
Own Heading			Turn Rate	ATARS | Seam
Pos/Neg Resolutions		New Res	Vertical Speed Limit	

Buffer Header Entry

Most Crit, Contr, ATARS, Start, 1st Threat, Valid Velocity

00 01*								Bearing
±	Co or No	alt Alt Magnitude						Range
Heading								Velocity
Valid	Turn Type							Vertical Speed

Position Entry (*00=Prox, 01=Threat)

Valid Data, Commanded

10			Spare		Miss Distance
CPA Bearing					Time to CPA
±	Co or No	alt CPA Alt Magnitude			A/C Info
A/C Info					A/C Info

Auxiliary Threat Entry

Fig. 34. Display Buffer Encounter Entries.

vertical speed, CPA bearing and altitude and time) are known or not, and thus whether or not the display can utilize them. If the encounter was not updated, the data fields are produced by coasting the last known position values to the current time via the rate quantities residing in the encounter file.

The display buffer creation routine must also insure that one and only one encounter entry contains a most critical bit, to insure proper display generation. Various error conditions could result in none or several encounter files having this bit set. Examples of these are:

1. the uplink position message with the most critical bit set was not received

2. the current scan message for the previous scan's most critical encounter was not received, hence it and the new most critical encounter are both so labelled

3. two ground sensors disagree on the most critical encounter

4. the ground logic fails.

The last chapter presents the onboard logic to either choose one most critical encounter when none exists or arbitrate when several exist.

The display buffer has been designed to meet the needs of any graphic or alphanumeric display device. Thus, just by changing the display subroutine to match the new display characteristics, the tracking software that produces this buffer can be used without modification.

8.0 AID USER SELECTABLE FEATURES

The Lincoln developed experimental ATARS graphics display, known as the Airborne Intelligent Display (AID), contains a number of selectable features to facilitate testing. While some of these user options may remain on operational systems, many others will be replaced by fixed settings at the values determined to be optimum.

The previous chapter has described the maximum information format ATARS display. Although in theory all the information on the display should be useful to the pilot, preliminary tests and observations have shown that the resulting screen is often too cluttered to be readable. Thus, several reduced display formats have been built into the AID. The gross amount of display information is controlled by a parameter called the display level, while the fine tuning within each level is controlled by three other parameters: screen range, proximity display mode, and proximity display priority. Also, the color of any display item can be altered as desired. The full complement of display formats possible via different settings of these parameters is described in this chapter. Also, the methods by which a user can enter values for each parameter are presented.

Since the AID is being used in an experimental system, various debug features have been built into it. These features, described in section 8.4, permit operation of both the ATARS ground system and the onboard avionics to be investigated. They also help to pinpoint the causes of any errors that might arise during the test program.

8.1 ATARS Display Levels

Ten levels of ATARS display, ranging from the full format described in the last chapter all the way down to resolution advisories only, with no graphic display or encounter information, have been defined for the AID. Figure 35 describes how much the information set is reduced as the level setting is lowered. Figure 36 provides an alternate description of the various levels by listing the format for each type of screen entity as a function of level.

The remainder of this section provides an expanded description of each level, along with notes and comments on the advantages and disadvantages of the ten formats. Figures 37 through 46 give pictorial examples of how the display screen would appear at each level for two different encounter mixes: two threats, and one threat and two proximities.

Level 9 - Maximum Information

This level provides all possible information on all encounters as well as the settings of the display parameters. Although apparently giving the pilot the ability to make the best decisions, the mass of screen information in actuality can prevent him from locating the key items before a new display appears. Also, so much alphanumeric information exists that some of it can be

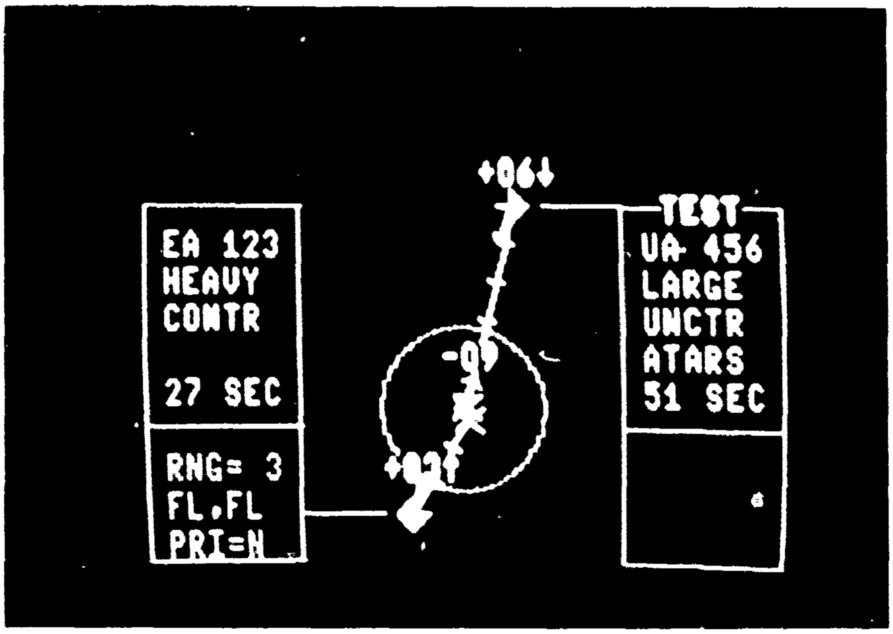
Level and Menu Name	Display Format
9 - ABS MAX	Full information format as described in section 7.1, with relative motion and aircraft information on up to two threats.
8 - TWO MAX	Same as 9, except that display parameter values are not listed.
7 - ONE MAX	Same as 8, except that relative motion and aircraft information is provided only for the most critical threat.
6 - TWO INF	Same as 8, except that altitude at CPA is no longer provided for either threat.
5 - ONE INF	Same as 7, except that altitude at CPA is no longer provided for the most critical threat.
4 - TWO THT	Same as 6, except that aircraft information is no longer provided for either threat, and thus only time to CPA is given in the sidebar areas.
3 - ONE THT	Same as 5, except that aircraft information is no longer provided for the most critical threat and the sidebar boxes are removed, although the time to CPA for the most critical threat is still shown on the side of the display.
2 - MIN HDG	Same as 3, except that neither relative motion information nor time to CPA is provided for any threat.
1 - MIN CTL	Same as 2, except that no heading vector is provided for proximity aircraft and no turn indications given for threat or own aircraft.
0 - ABS MIN	Only resolution advisories are displayed, with no graphic encounter picture at all.

Fig. 35. Reduction of Display Format with Level.

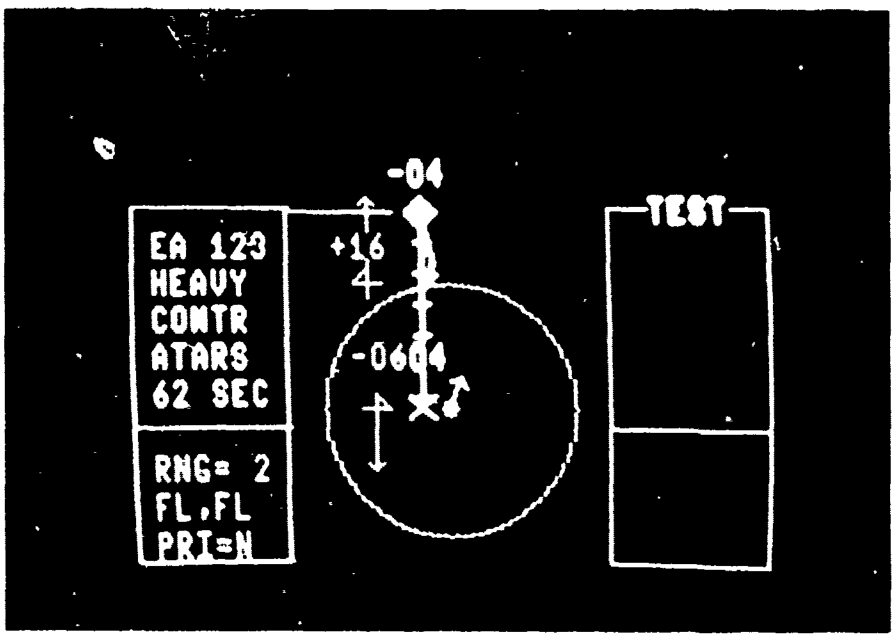
Feature

Level	Resolution Advisory	Threat Position	Relative Motion	Sidebar Information	Proximity Position	Own Aircraft
0	Present	None	None	None	None	None
1		Symbol, status, altitude, heading, velocity	None	None	Symbol, status, altitude	Heading, velocity, range ring
2		above + turn status	None	None	above + heading, velocity	above + turn status
3			CPA range and bearing on most critical threat	CPA time on most critical threat		
4			same as above on two threats	same as above on two threats		
5			same as above on most critical threat	CPA time and aircraft information on most critical threat		
6			same as above on two threats	same as above on two threats		
7			CPA range, bearing, and altitude on most critical threat	same as above on one threat		
8			same as above on two threats	same as above on two threats		
9			same as above on two threats	same as above on two threats + parameter values		

Fig. 36. ATARS Display Features vs. Level.

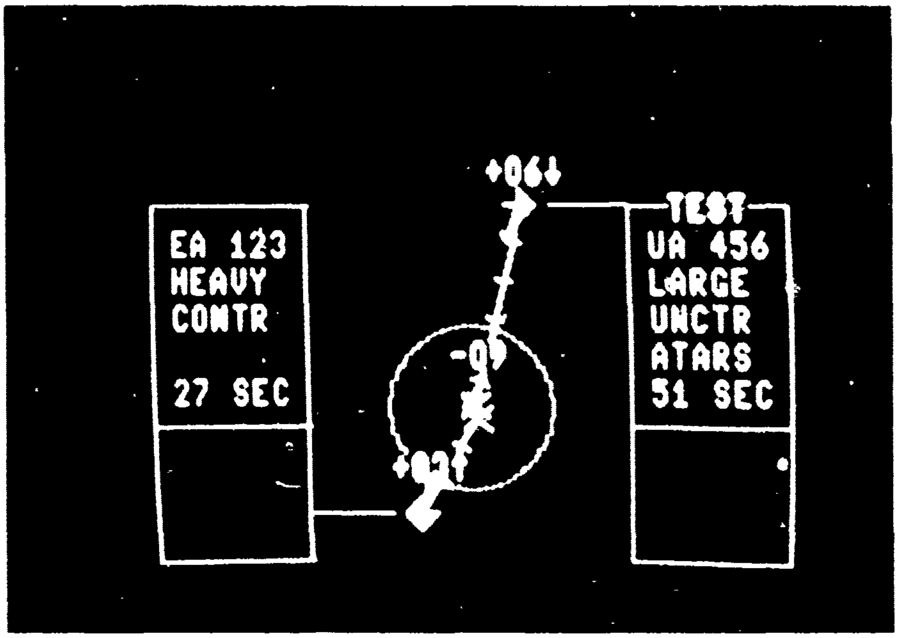


2 THREATS

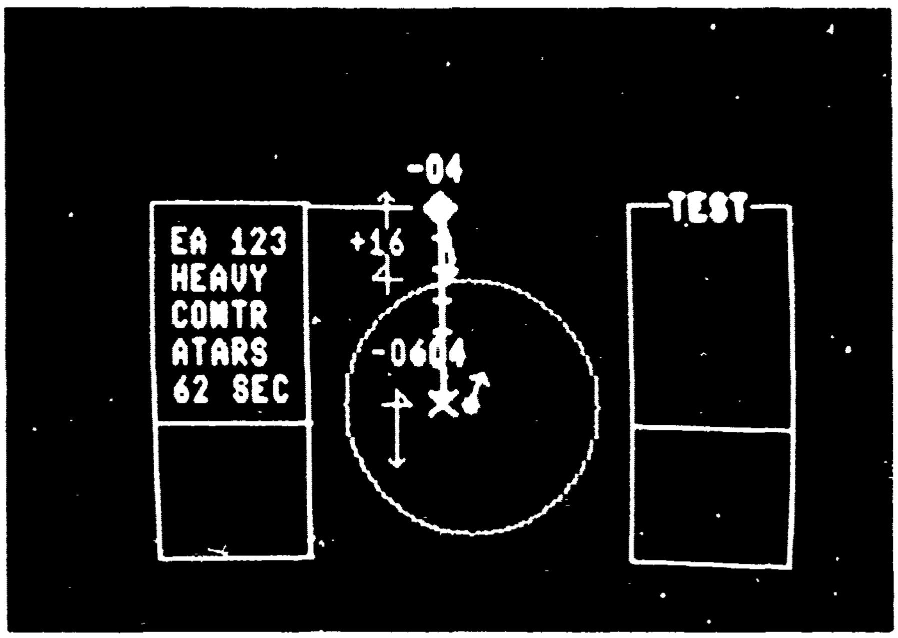


1 THREAT, 2 PROXIMITIES

FIG. 37. SAMPLE LEVEL 9 SCENARIOS

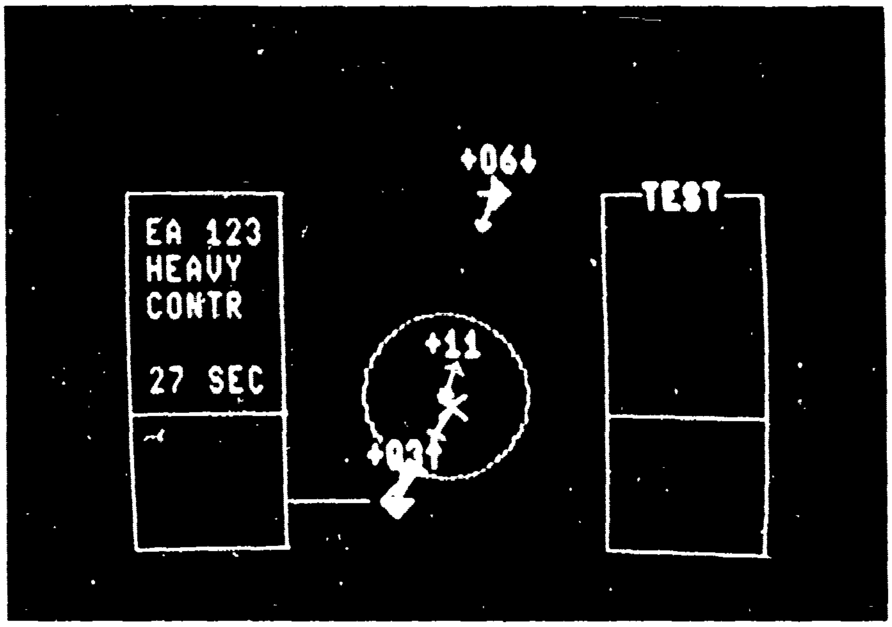


2 THREATS

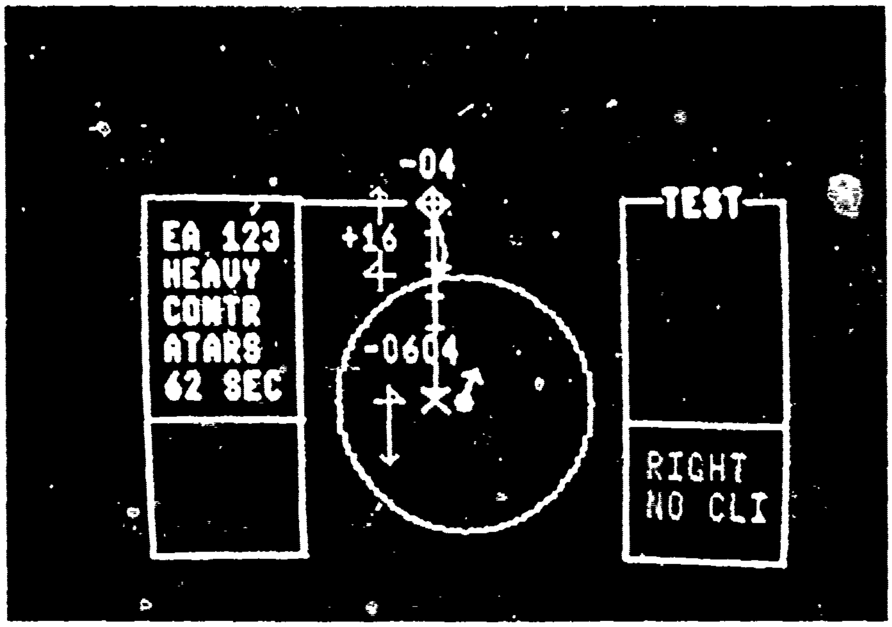


1 THREAT, 2 PROXIMITIES

FIG. 38. SAMPLE LEVEL 8 SCENARIOS

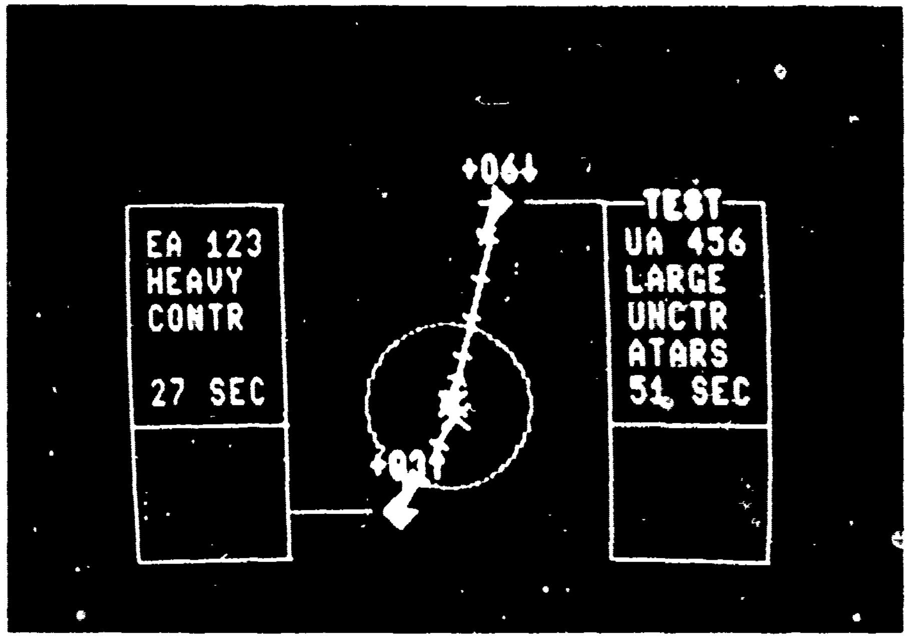


2 THREATS

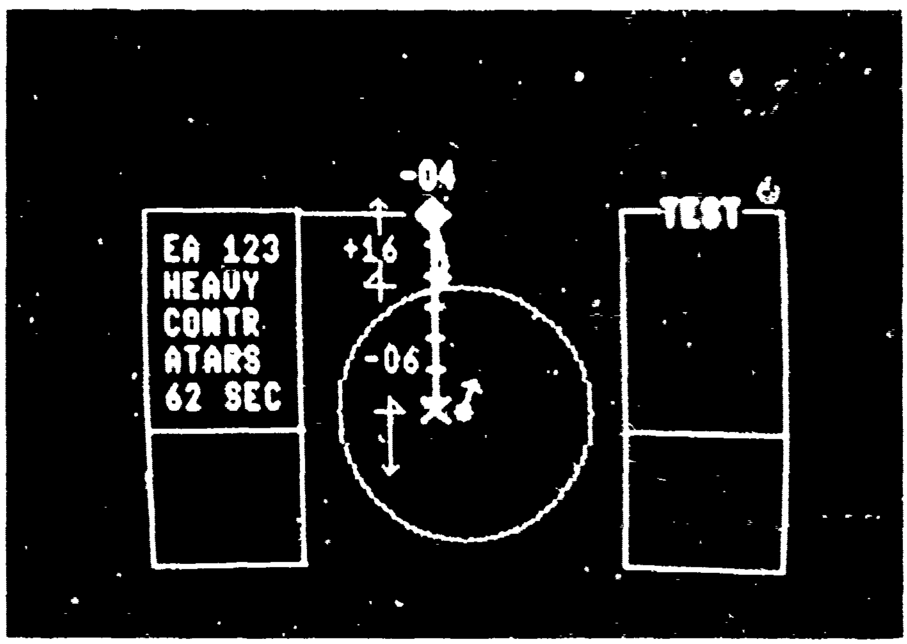


1 THREAT, 2 PROXIMITIES

FIG. 39. SAMPLE LEVEL 7 SCENARIOS

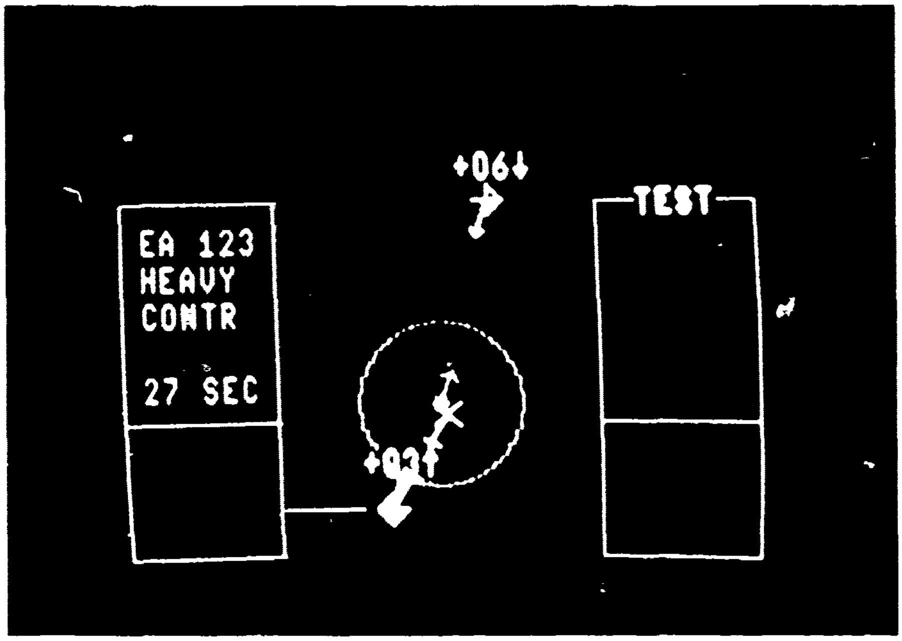


2 THREATS

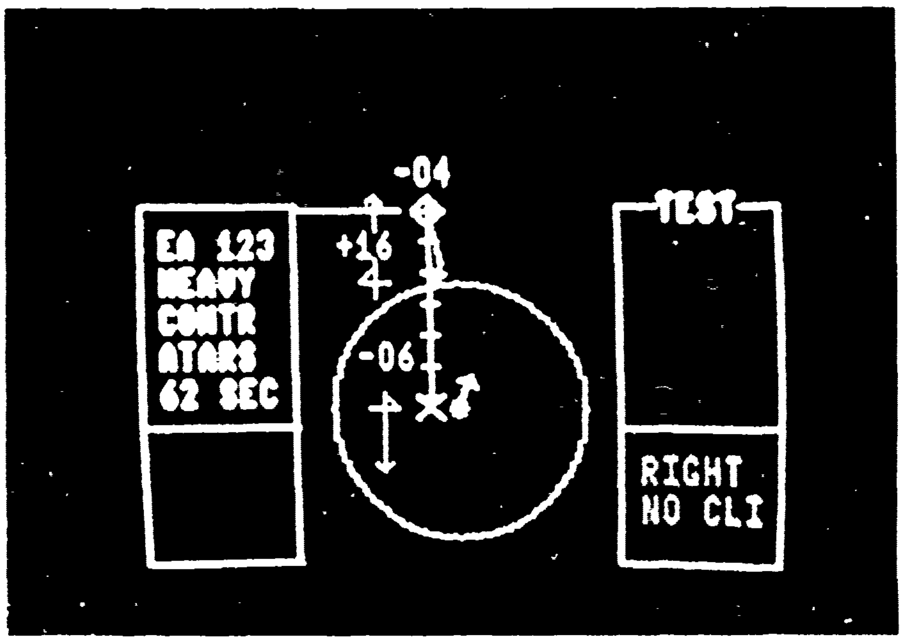


1 THREAT, 2 PROXIMITIES

FIG. 40. SAMPLE LEVEL 6 SCENARIOS

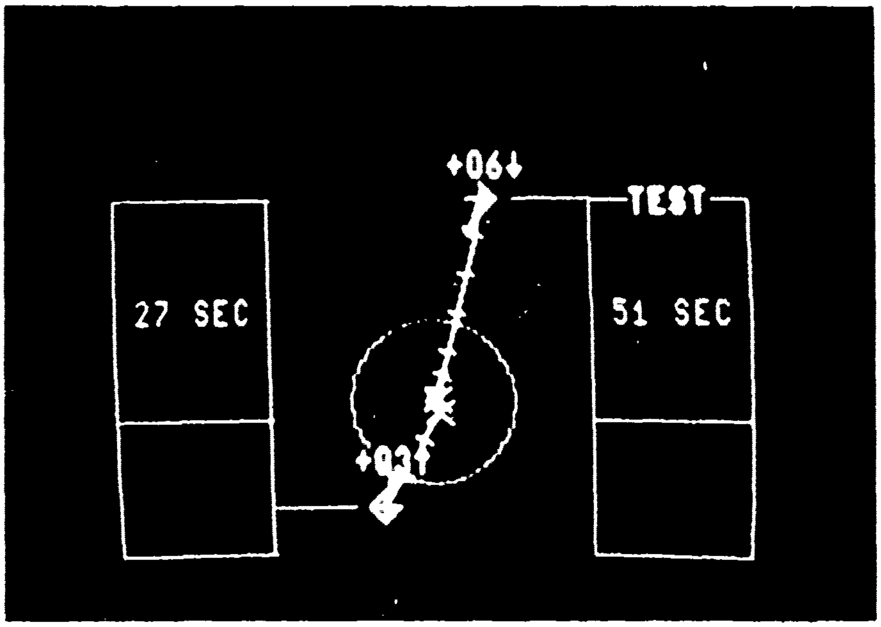


2 THREATS

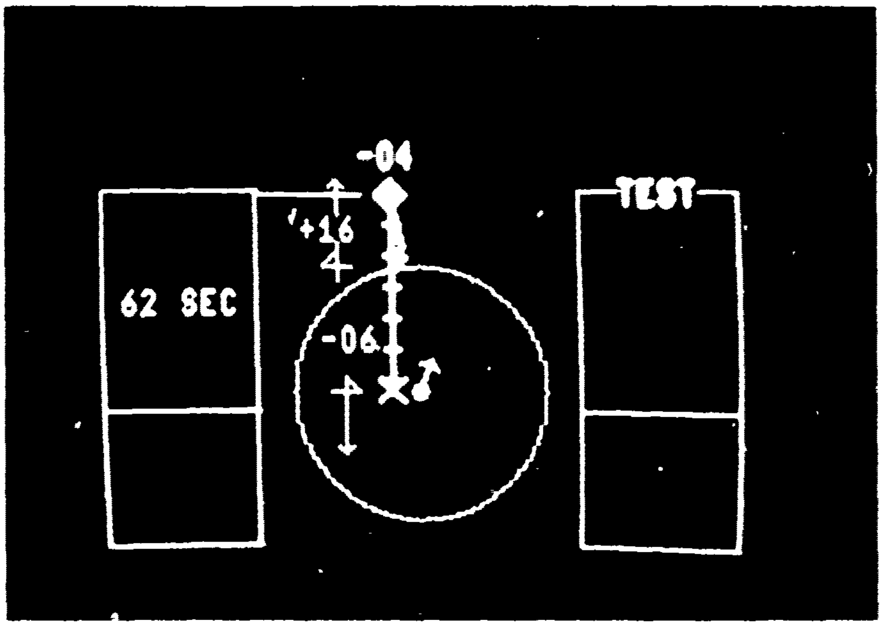


1 THREAT, 2 PROXIMITIES

FIG. 41. SAMPLE LEVEL 5 SCENARIOS

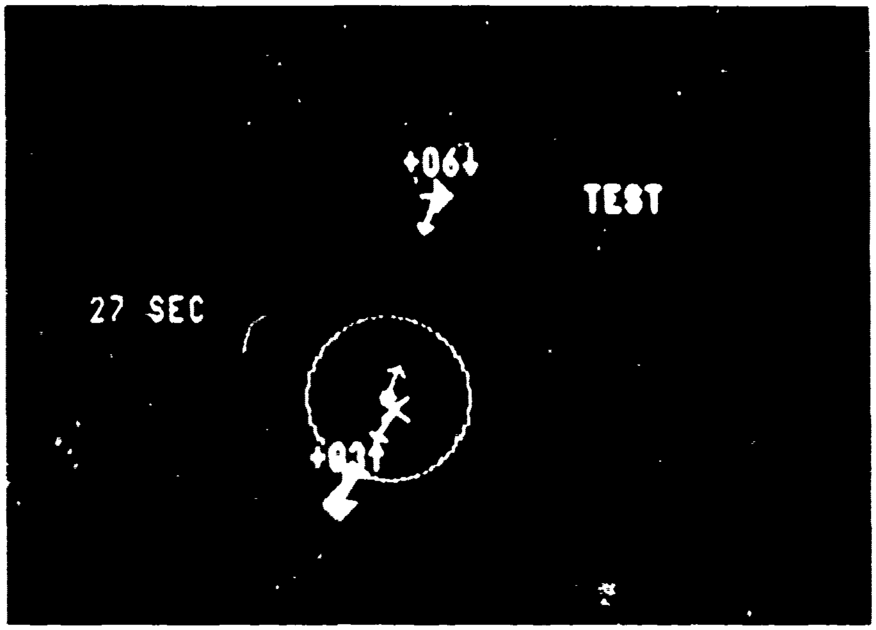


2 THREATS

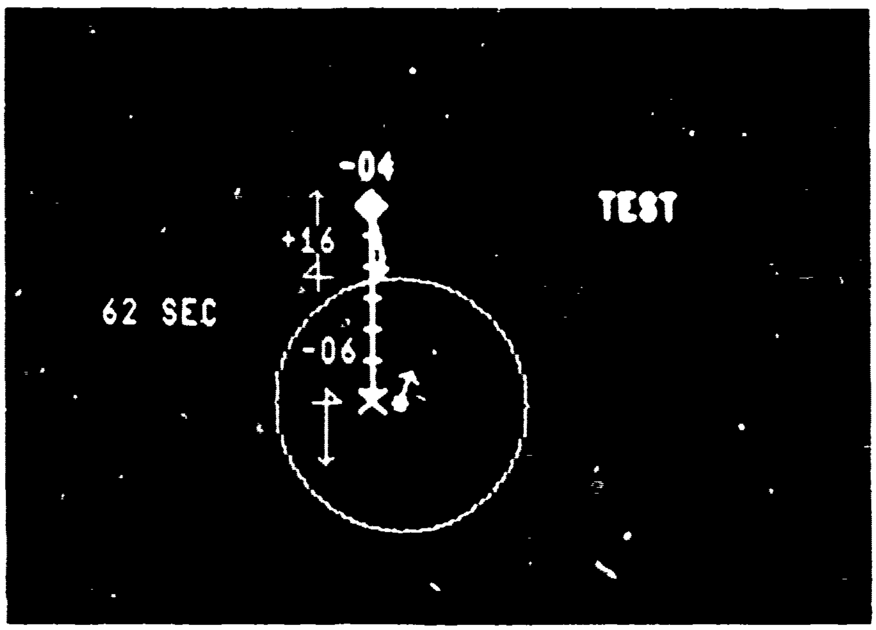


1 THREAT, 2 PROXIMITIES

FIG. 42. SAMPLE LEVEL 4 SCENARIOS

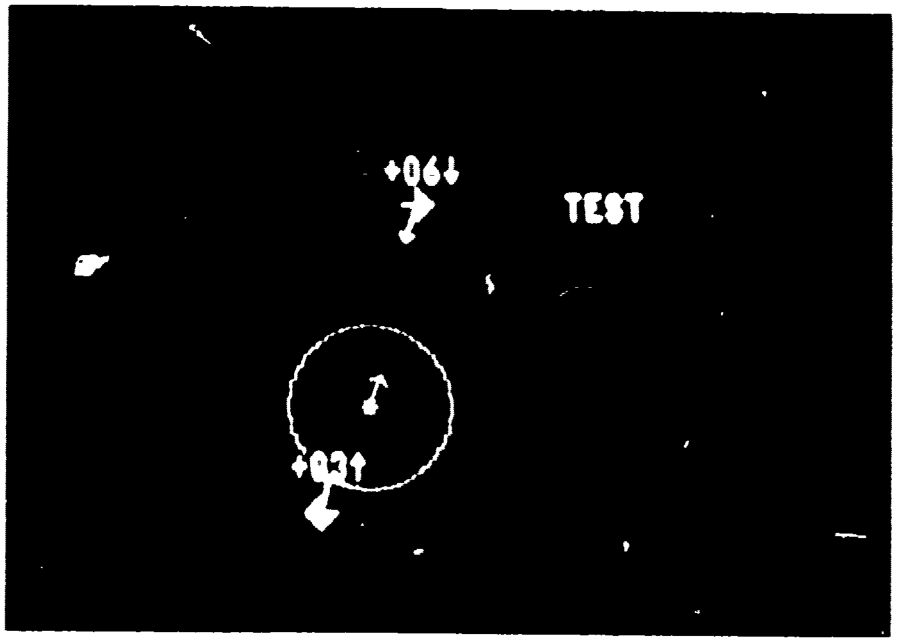


2 THREATS

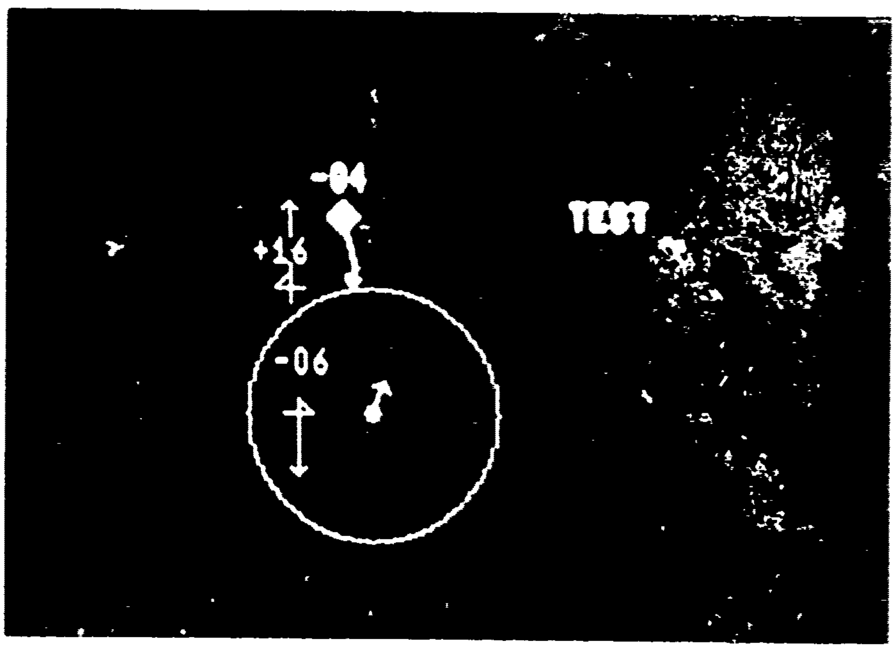


1 THREAT, 2 PROXIMITIES

FIG. 43. SAMPLE LEVEL 3 SCENARIOS

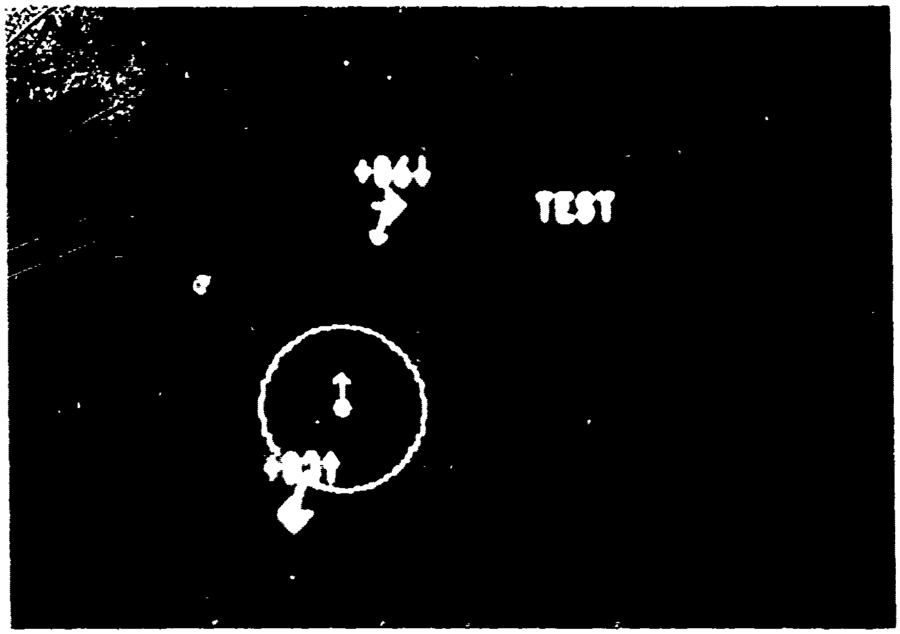


2 THREATS

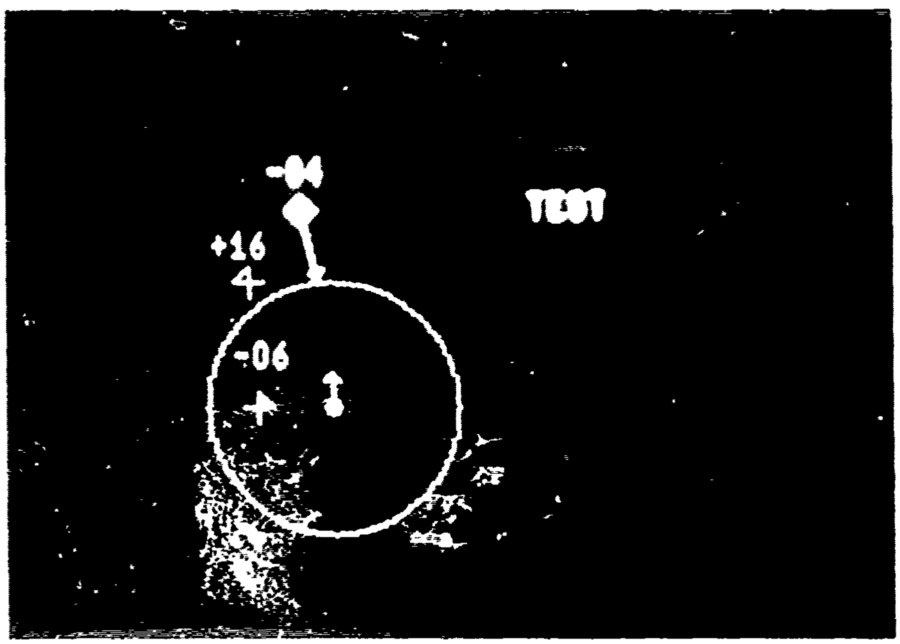


1 THREAT, 2 PROXIMITIES

FIG. 44. SAMPLE LEVEL 2 SCENARIOS

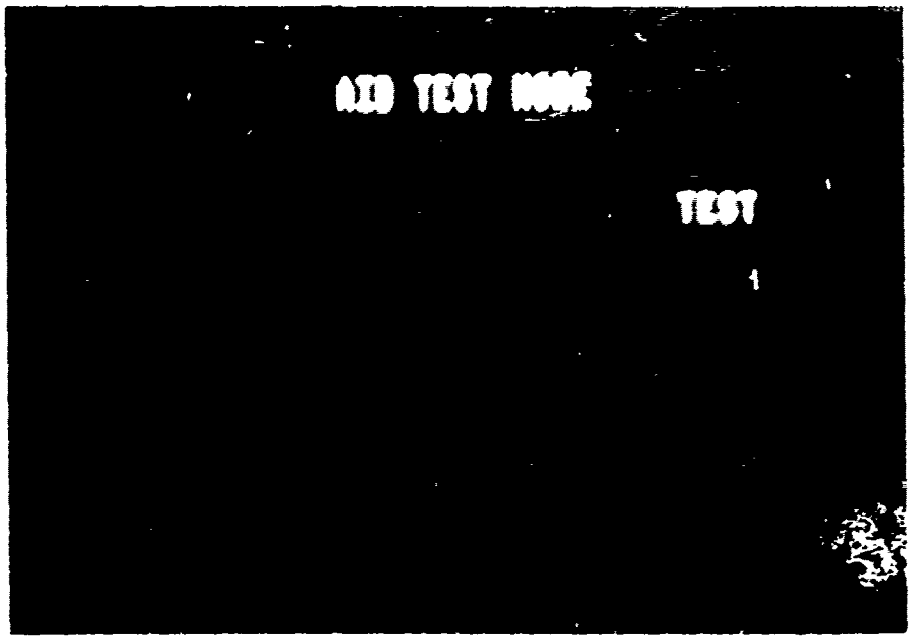


2 THREATS

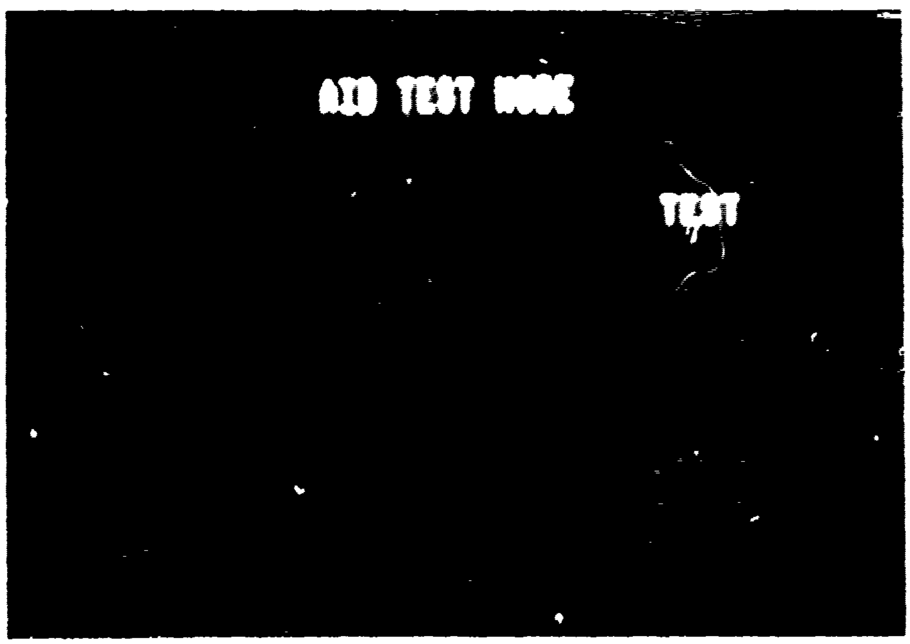


1 THREAT, 2 PROXIMITIES

FIG.45. SAMPLE LEVEL 1 SCENARIOS



2 THREATS



1 THREAT, 2 PROXIMITIES

FIG.46. SAMPLE LEVEL 0 SCENARIOS

overwritten and thus lost. This is particularly true for altitude at CPA. Both level 9 displays in Fig. 37 suffer this problem. In one case, the entire altitude is missing, while in the other its sign has been lost. In conclusion, although level 9 is of interest in showing the amount of data resident in ATARS, it is probably not a viable operational choice.

Level 8 - Two Threat Maximum

This level provides the identical encounter display as the previous level 9. The only difference is that the display parameter values are no longer posted. If, as expected, a pilot will initialize these parameters to accustomed values, and not change them during a flight, eliminating the parameter data reduces screen clutter at no cost. However, if parameter changes are found to be useful according to the ATARS situation, the pilot would need to know their current values. If this is found to be true during tests, introducing the parameter posting into other lower levels may be required.

Level 7 - One Threat Maximum

If it is true that a pilot can concentrate and plan strategy on only one threat at a time, then removing the relative motion display for the secondary threat will help him in this effort. The second threat data will no longer divert his attention or interfere with the display of the primary information. The current position and heading of the secondary threat will still remain on the screen, of course, so some avoidance information would still exist.

Level 6 - Two Threat Information

This level has removed the altitude at the threat's closest point of approach. Because of its positioning near the center of the screen, this alphanumeric tag tends to interfere with other more important data. If CPA altitude is felt to be useful, it could be displayed in the sidebar areas. All other threat information, namely relative motion, range and bearing and time to CPA, and aircraft information, still exist on this level.

Level 5 - One Threat Information

This level is the same as the previous level 6 except that the auxiliary threat information is provided for only the most critical threat. The discussion under level 7 applies here as well.

Level 4 - Two Threat Relative Motion

This level has further reduced the maximum display format by removing the aircraft information data from the screen. This data, namely aircraft type, airline operator, and flight number, was intended (when available) to aid the pilot in identifying the threat aircraft. However, it does take time to read and removes the pilot's attention from the graphic area of the display. Only testing and evaluation can determine whether this information is a help or a

hindrance, and thus whether level 4 is an improvement over level 6. The threat relative motion information, namely the relative motion line, CPA range and bearing, and time to CPA, still remain for both threats at this level.

Level 3 - One Threat Relative Motion

This level presents the same level of threat data as level 4, but only for the most critical threat. Thus, the discussion under level 7 is again applicable. In addition, since the total sidebar information has now been reduced to a single time to CPA for the most critical threat, the side boxes are no longer required. This reduction alone has led many observers to favor level 3. The combination of the most important relative motion information for the most critical threat and a minimum of screen clutter makes this level a strong favorite to be chosen as the best. It is currently the default level for the AID display.

Level 2 - Minimum Display with Headings

This level provides full information on the current positions, status, and headings of all aircraft, including the turn status of the own and all threat aircraft. No relative motion or CPA data is any longer provided, even for the most critical threat. This level will be chosen if relative motion information is rejected by pilots. Possible reasons for such a decision are that it varies too much from scan to scan to be useful or that it takes too much time and effort to assimilate. Only testing can lead to proper evaluation of relative motion data.

Level 1 - Minimum Display

This level provides the minimum graphic display felt to be feasible for ATARS. The current range, bearing, and altitude is provided for all encounter aircraft. In addition, the control status, namely whether or not ATARS equipped, whether or not controlled, and whether or not receiving an ATARS resolution advisory (threats only), is shown. Finally, the heading arrow for threat aircraft is drawn to provide the minimum level of motion data that would still provide pilots with some ability to plan strategy. This level provides a lower bound for ATARS presentations.

Level 0 - Resolution Advisories Only

Some pilots may not want to take any collision avoidance action at all on their own. For them, this level is ideal. However, since no graphic display of any kind is provided, pilots will receive no advance warning of the resolution advisory.

It is of course clear that many other levels of ATARS display could be developed. If during testing certain features are found to be useful, they could be added to levels that do not presently contain them. For example, aircraft information could exist even at level 1 if so desired.

After testing is completed, two different types of decisions could result. First, one level could be found to be far superior to all others, and only it is provided in commercial displays. Alternatively, several levels could be found appealing to various groups of pilots, and pilot option would remain built into the displays. The first is cheaper, the second more flexible.

8.2 AID Display Parameters

The previous section discussed how a pilot can select the ensemble of information he would like on his ATARS display. This section describes the display parameters that determine the exact manner in which this information is presented. In particular, they control the scale of the display region, the degree of proximity detail as a function of threat situation, the relative priority of ATARS versus other data link uses, and the color employed for each feature of the display.

8.2.1 Screen Range (RNG)

The RNG parameter defines the maximum distance from the own aircraft within which all encounter positions are guaranteed to be in the displayable region. As shown previously in Fig. 26, this region is rectangular rather than circular, so that longer distances are displayable at most bearings. Also, the region was designed to extend a minimum distance of 2*RNG in the forward direction, as closing speeds are higher for head-on encounters. Any encounter that is out-of-scale for the display region is shown as a triangle without alphanumeric altitude on the display perimeter. Thus, although it still is shown, range and altitude information is lost.

Two different types of screen range settings are possible: manual and automatic. With the former, the screen scale remains constant from scan to scan at the pilot set value. With the latter, however, the scale will vary according to the encounter situation, and thus changes from scan to scan are possible.

To establish a manual range, RNG is set to a value between 2 and 8 nautical miles inclusive. This value is then used as the constant screen range. The remaining integer values, if set by the user, signal an automatic range mode. The interpretations are as follows:

RNG = 0: each scan, choose the smallest screen range setting that permits all encounters to be within the displayable region.

RNG = 1: each scan, choose the smallest screen range setting that permits all threat encounters to be within the displayable region (proximity encounters may be off scale); if no threat encounter exists on a scan, proceed as if RNG = 0.

RNG = 9: each scan, choose the smallest screen range setting that permits the most critical encounter to be within the displayable region; other threat or proximity encounters may be off scale.

The screen range can vary between 2 and 13 nautical miles in these automatic modes. Each scan, the proper value is calculated by the display processor from the active encounter range and relative bearing data. Note that range data alone is not sufficient, as the displayable area has a different physical length for each bearing. Thus, for example, if a single encounter at 9.7 miles exists, the screen range would have to be set to 10 miles if the encounter were at 90°, but only 7 miles if the bearing were 135°, and just 5 miles if it were straight ahead.

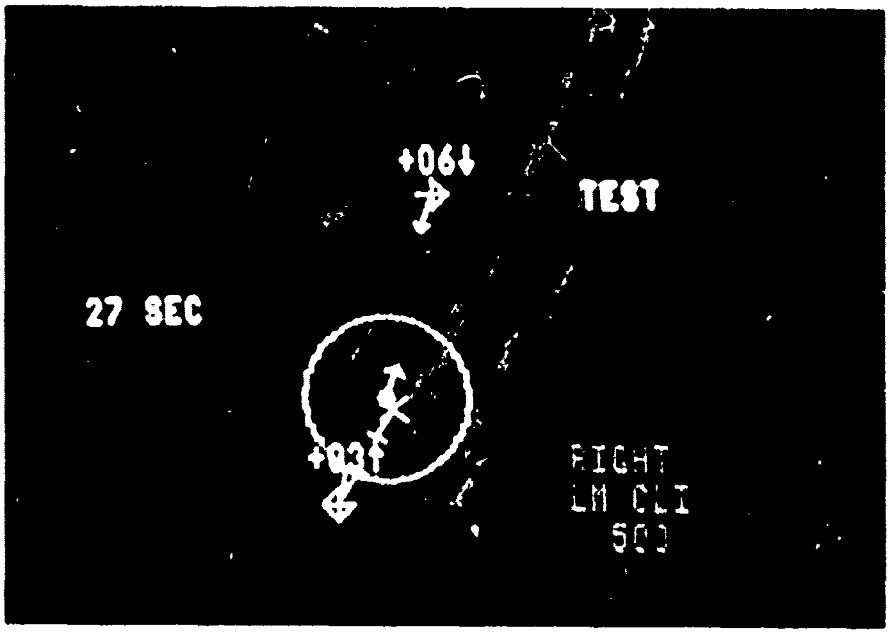
Automatic range modes have both advantages and disadvantages. The main advantage is that no pilot intervention is required to produce the best display scaling. In particular, every time a threat pops up, the display will be optimum for pilot data assimilation. With manual range modes, the setting could be too small, producing off-scale loss of information, or too large, producing relative motion data too compressed to be readable. The main disadvantage of the automatic modes is sudden jumps in the frame of reference. Each time the screen range changes, the pilot must reorient himself before he can continue his monitoring of the encounter status. Only testing can determine how serious such jumps are to pilot concentration.

Figure 47 illustrates how proper and improper range settings can effect the ATARS display. The top picture was made using an automatic mode, and so all data appears, as readably as possible. The bottom picture corresponds to RNG=2. Both threats are now off scale, and current position data is lacking.

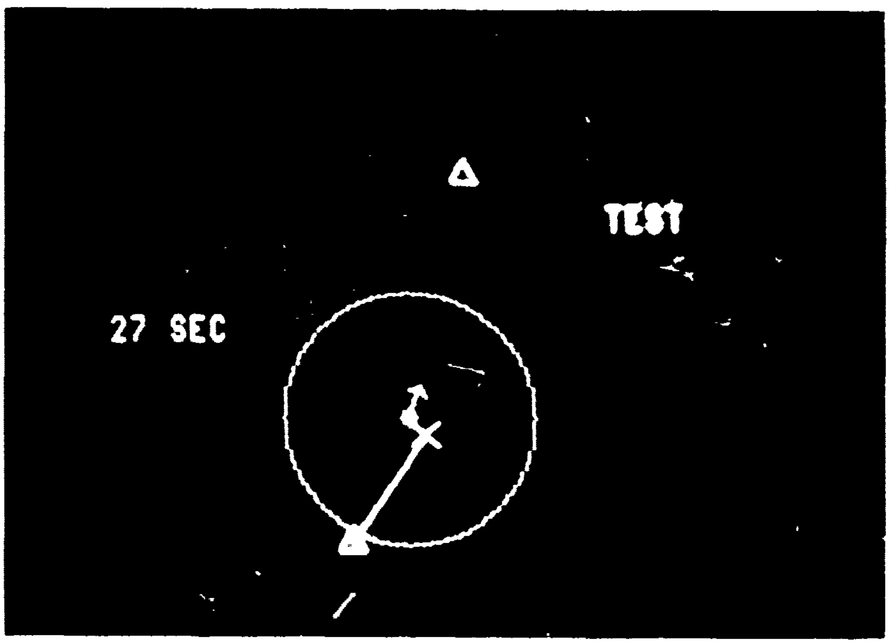
The AID default value is RNG=9, providing an optimum display for the most critical encounter.

8.2.2 Proximity Display Mode (PDM)

Proximity encounters are much less important to the pilot than are threats. In particular, a pilot must make a positive reaction to the presence of a threat, while a proximity advisory is basically informatory in nature. Thus, the pilot may not desire the complete position, altitude, and heading format for a proximity as defined in the previous section. This may expecially be true when a threat encounter also exists, as this full representation may overcrowd the display and obscure the threat information. In fact, if great care is not taken in the display processor, the proximity alphanumerics or heading vector could overwrite some of the threat features. (The AID has this drawback; commercial displays should avoid it). For this reason, a pilot may find a simple position symbol for the proximity better suited to his needs.



RNG = 3



RNG = 2

FIG. 47. EFFECT OF RNG PARAMETER CHANGE

Some pilots may only want traffic advisory information in threat situations. Such a pilot will be uninterested in seeing any proximity representation at all when no threats exist. However, when a threat is present, he will need at least an indication of the position of proximity aircraft to fully understand the encounters.

In order to allow the pilot to select his desired combination of proximity formats for threatening and non-threatening situations, the system is equipped with a proximity display mode parameter. The four states of this parameter provide the following proximity format options:

PDM Option	When a threat exists	When no threat exists
a	Full	Full
b	Point	Full
c	Point	Point
d	Point	None

where:

Full: + symbol with ATARS and control indicators, altitude alphanumerics, heading vector

Point: + symbol with ATARS and control indicators

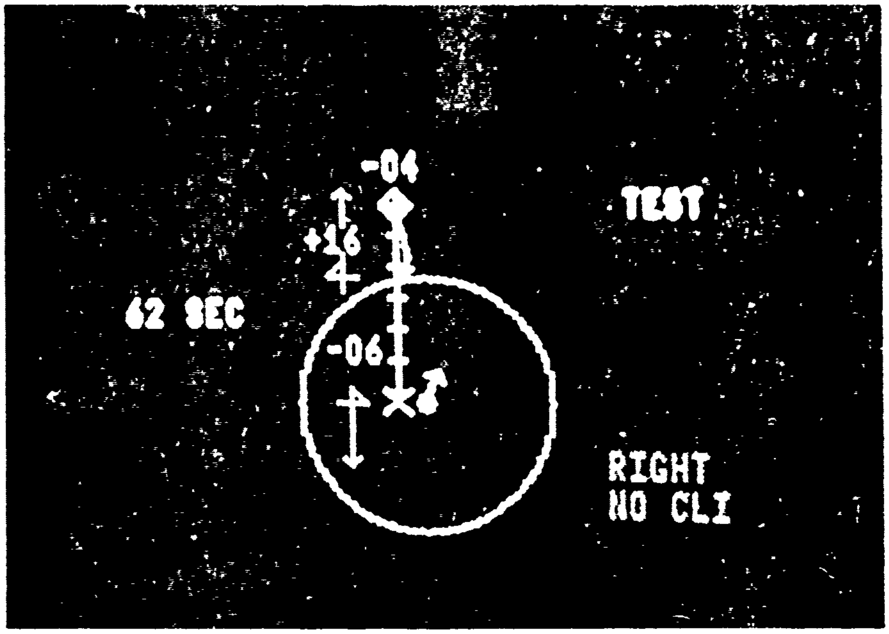
None: no indication

The first option provides maximum information at all times. The second reduces the potential clutter when threats are present. The third signifies the lower importance of proximity advisories at all times while still noting their presence. The final one provides proximity presence data only when threats co-exist and maneuvers could be contemplated.

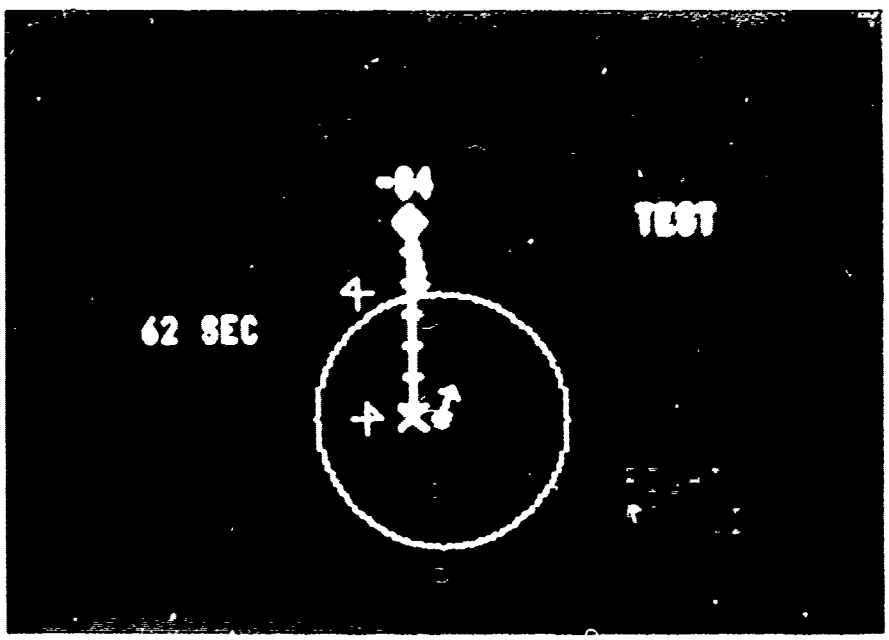
Observations at Lincoln of screen clutter during threats have led to the belief that it is a sufficiently serious problem that the PDM default option has been set to b, point/full. Figure 48 indicates the screen appearance differences of point versus full format when threats are present.

8.2.3 Proximity Display Priority (PRI)

The AID is used to display ATARS encounters, data link messages, and weather radar data. The most important of these competing users is clearly ATARS when a threat situation exists. Thus, as long as a threat encounter is active, ATARS is guaranteed access to the screen. However, as described earlier, tactical data link messages, also important to the pilot, can co-exist on the display with ATARS.



PDM FULL



PDM POINT

FIG.48. EFFECT OF PDM PARAMETER CHANGE

Proximity advisories, on the other hand, are not critical and do not require pilot action. Thus, a pilot may not want them to preempt the screen when he is in the midst of requesting or reading a data link message. He may not even wish to see them while he is viewing weather data, normally the lowest priority system user. The proximity display priority parameter permits the pilot to rank non-threat ATARS situations according to his personal view of their importance.

The screen access priority structure recognizes three priority levels: high, normal, and low. As explained in chapter 7, a current display can be preempted only by a display of higher priority; equal or lower priority displays are buffered until their turn arises. The fixed priority assignments are currently as follows:

high: ATARS with threat encounters
normal: data link messages, menus
low: weather radar

Thus, if PRI is set to high, any ATARS display, with or without threats, will appear immediately and preempt other display uses. If PRI is set to normal the pilot will be able to complete his ongoing data link interaction before non-threat ATARS displays will appear; weather data, however, will immediately disappear. Finally, if PRI is set low, non-threat ATARS displays will appear only when the screen is not currently in use.

The AID default value for PRI is normal.

8.2.4 Feature Colors

To provide human factors engineers with the flexibility to determine proper color settings for the ATARS display, each feature in the AID display has a separate parameter controlling its color. The list of features, and the current default color for each, is provided in Figure 49. Figure 28 presented a color picture of a current ATARS display with these color choices.

The AID has 8 different colors available for display, with Figure 49 also specifying this list. Any of these colors can be assigned to a feature, independent of any other feature. The next section describes the procedure for specifying the desired color to feature assignment.

Feature #	Feature	Default Color
0	Resolution Advisory	Red
1	Threat Encounter	White
2	Proximity Encounter	Green
3	Sidebar Legend	Yellow
4	Own Aircraft	Yellow
5	Threat Sidebar Leader	Yellow
6	Parameter Posting	Green

Color #	Color
0	Black
1	Blue
2	Green
3	Light Blue
4	Red
5	Violet
6	Yellow
7	White

Fig. 49. ATARS Features and Colors.

8.3 ATARS Parameter Entry Procedures

The ATARS display parameters described in the previous two sections are all alterable by pilot interaction with the AID via the control keyboard. Any of these parameters can be changed at any time, whether or not an ATARS display currently exists. However, the procedure will differ between these cases for some of the parameters.

A special control key, labelled RNGE, has been provided for entering new values of the screen range parameter. By pressing this key, followed by the pressing of any numeric key (0 through 9), a new screen range value is defined, with the corresponding meaning as described in section 8.2.1. This action can be taken at any time, independent of the screen usage status of the AID. If an improper key is pressed by accident following RNGE, the system will wait for a proper entry. Thus, the only procedure for cancelling a screen range change once begun is to enter the current parameter value.

All other AID parameters are altered through reference to the proper ATARS menu. Accessing an ATARS menu while the system is in a data link mode (no ATARS display on the screen) requires proceeding first through the data link menu. This menu, illustrated in Figure 50, appears when the MENU key is pressed. By then pressing the numeric 0 key, as stated on the selection list, the first ATARS menu, shown in Figure 51, appears. The pressing of the MENU key is optional, as the system resides in the acceptance state for data link menu entries in any event. Thus, a numeric 0 entry by itself will suffice to access the first ATARS menu.

When the system is currently in an active ATARS state, that is when ATARS scenarios are being displayed, the system residency switches to the first ATARS menu. Thus the two steps of pressing the MENU and numeric 0 keys are no longer required, as this menu is already active. In fact, pressing the MENU key will sound an invalid entry tone, while the numeric 0 entry will be ignored. (It is treated as an exit from the first ATARS menu, which merely leaves the system where it already was.)

If the operator actually needs to view the first ATARS menu during an active ATARS period, because he has forgotten its selection ordering, he must use the following procedure. First, he must press numeric 3, which sets the proximity priority to low. Then he can press the MENU key to fall back to the normal priority data link menu whenever no threats exist. Finally, a numeric 0 entry retrieves the first ATARS menu. This menu will immediately be preempted, though, if a high priority threat encounter appears.

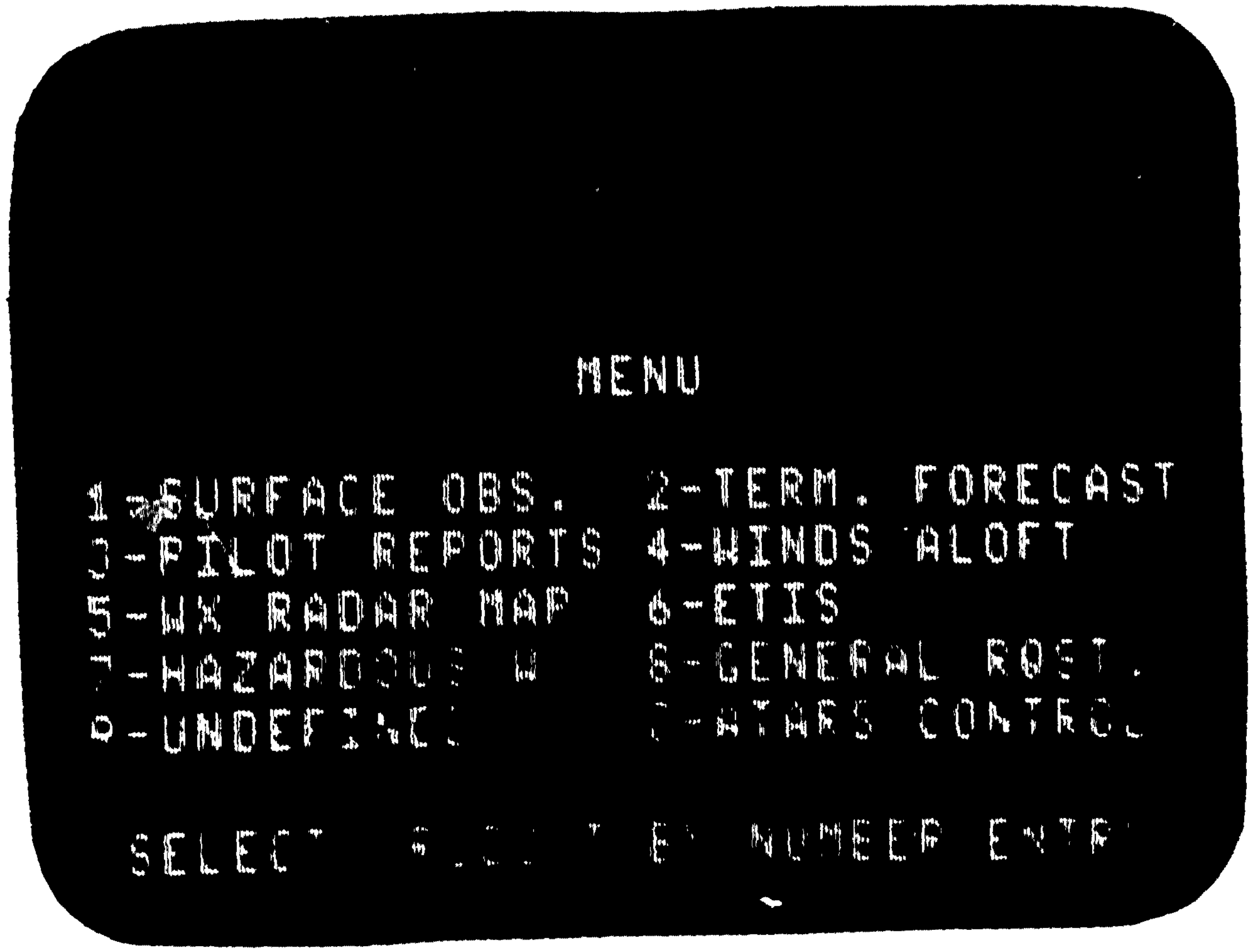


FIG. 50. DATA LINK MENU

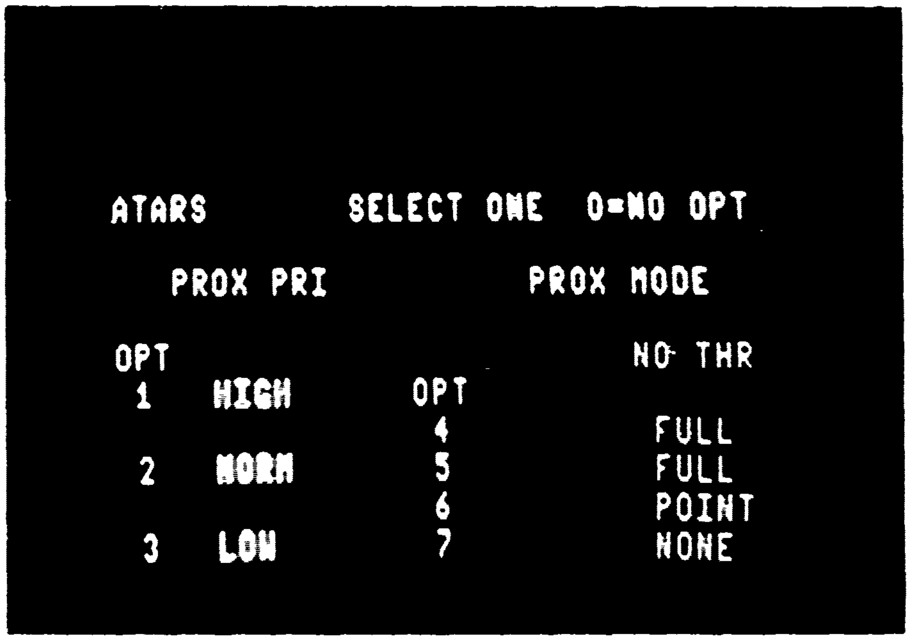


FIG. 51. FIRST ATARS MENU

This first ATARS menu provides the means for changing either the proximity display priority (PRI) or the proximity display mode (PDM): a numeric entry of 1 through 3 sets the value of PRI, while a numeric entry of 4 through 7 sets a new value of PDM. The interpretations of each integer entry are as defined in Figure 51; the detailed explanations of each parameter setting were provided in sections 8.2.2 and 8.2.3.

If the operator accessed this menu accidentally, such as by making the wrong selection from the data link menu, he can exit by pressing the numeric 0 key. The other remaining numeric values, namely 8 and 9, lead to other ATARS menus: 8 for display level selection, and 9 for color selection. Neither of these options are described on the menu, as they are felt to be most applicable for test purposes. Thus, they are "hidden" from the pilot. The pressing of any non-numeric key while the menu is active is ignored by the system.

The ATARS display level menu is presented in Figure 52. As shown, any of the ten possible levels, 0 through 9, can be set by pressing the corresponding numeric key. Section 8.1 defined each such level in detail. The only exit from this menu is by pressing a valid key.

Finally, pressing a 9 from the first ATARS menu permits changing any of the screen feature colors. No color menu will appear, as the AID has insufficient remaining memory for its definition. Two numeric key entries are required to alter a color parameter: the first selects the feature whose color is to be changed, the second selects the color to be used. Figure 49 presented the number-to-selection lists for each entry. Any invalid keys are ignored for either entry.

Figure 53 presents detailed examples of the procedures described in this section for altering each of the AID parameters. The first example demonstrates the preferred method for expanding the screen range to bring an encounter within scale, which is to invoke the automatic all-encounter mode. The second example indicates that while ATARS is active, the first ATARS menu is set to accept inputs, and thus only a single key entry is required to change the PDM setting. The third example shows how the ATARS menu is accessed when ATARS is not currently being displayed. In that case, the data link to ATARS menu transition is required. The last two examples demonstrate the methods for making selections from the second and third ATARS menus, both from data link and ATARS system states.

8.4 AID Debug Features

The AID system has several built-in features to permit verification of the proper operation of the overall ATARS system and to help in pinpointing the sources of errors during system failure. The main such features are uplink message printout, input and output ATARS buffer recording, and memory dump upon operator command.

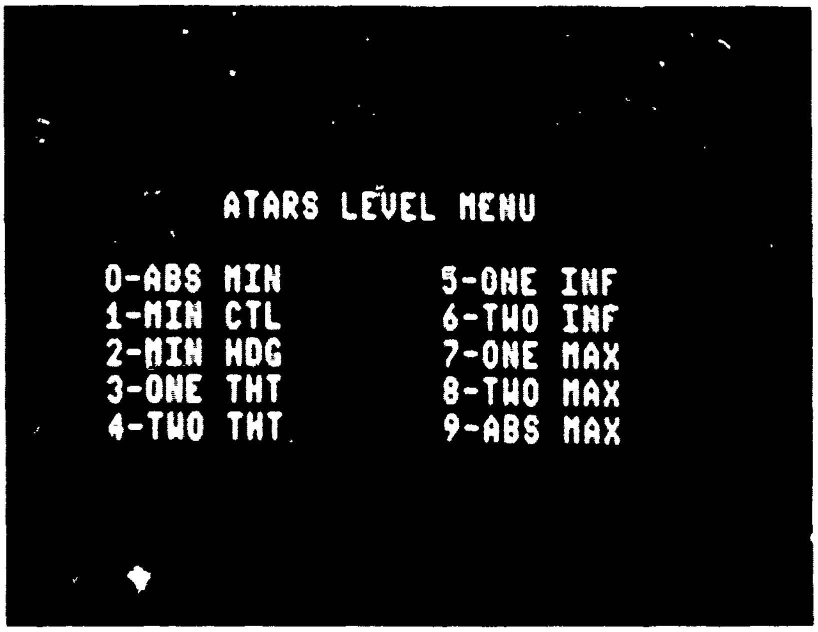


FIG. 52. ATARS LEVEL MENU

Example 1: Screen Range Adjustment

Situation: The current ATARS display contains a triangle, indicating an off-scale encounter. The pilot wishes to expand the screen range to locate the encounter.

Procedure:
1. Press RNGE key on keyboard.
2. Press numeric key 0.

Result: Screen range increases enough to include the off-scale encounter. If the pilot prefers a manual screen range setting, he can estimate the encounter range and set the screen range parameter accordingly.

Example 2: Proximity Mode Change

Situation: Full format proximity encounter representations are making it hard for the pilot to read the data on a threat encounter.

Procedure:
1. Press numeric key 5.

Result: The proximity encounter representations change to a point format as long as a threat exists.

Example 3: Proximity Priority Change

Situation: The pilot is viewing low priority weather data. Proximity encounters, set at normal priority, have been interrupting his display.

Procedure:
1. Press MENU key (optional) - data link menu appears.
2. Press numeric key 0 - ATARS menu appears.
3. Press numeric key 3.

Result: ATARS proximities are now low priority, and so can no longer preempt the equal priority weather data.

Fig. 53. ATARS Parameter Change Examples (1 of 2).

Example 4: ATARS Level Change

Situation: The ATARS display is at level 2, producing no relative motion data for a threat. The pilot decides such information would aid in his selection of avoidance maneuvers.

Procedure:
1. Press numeric key 8 - accesses level menu (no menu appears).
2. Press numeric key 3.

Result: The display is now at level 3, and CPA range, bearing, and time will appear for the threat.

Example 5: Color Change

Situation: A human factors engineer wishes to study the effect of light blue threat information on pilot awareness and comprehension in his next test.

Procedure:
1. Press MENU key (optional) - data link menu appears.
2. Press numeric key 0 - ATARS menu appears.
3. Press numeric key 9 - accesses color menu (no menu appears).
4. Press numeric key 1.
5. Press numeric key 3.

Result: Threat graphics (feature 1) will now be drawn in light blue (color 3).

Fig. 53. ATARS Parameter Change Examples (2 of 2).

Each COMM-A message received by the AID is automatically printed on the onboard printer. The fields printed per message are the ADS code, the 48 bit message field, and the scan number. By checking the list of messages against the ones that were expected, the operation of the ATARS ground system, data link message handler, DABS uplink control, and air link can be examined. The scan number is set by the AID according to its input timing rules, and thus proper interrupt and timer operation can be checked via its value sequence.

There are two main buffers utilized by the onboard ATARS software. The first is the input buffer, which receives a field unpacked version of each ATARS COMM-A. If its messages match those printed by the printer, message allocation and task scheduling have performed properly. The second buffer is the display buffer, which defines the picture to be drawn on the screen. If it has the proper entries, the ATARS correlation and tracking software must have performed properly.

Knowledge of these buffers permits non-real-time playback and debugging of the ATARS onboard software. If the first is correct, but errors appear in the latter, the correlation and tracking software can be stepped through piece by piece once the input buffer has been manually entered. Similarly, if an inexplicable display ever appears, the display buffer correlated to it can be entered and the display software exercised step by step.

To permit these tests, a full RAM is dedicated to recording the two buffers. It can be printed out when desired as described below. This RAM can hold the last thirty scans on which ATARS data was present. Thus, sufficient time exists for a real-time problem to be recognized, several scans of data viewed to identify its characteristics, and the system halted without any required data being overwritten.

Should the onboard ATARS system enter an error condition or an infinite loop, the operator can enter the numeric key sequence 5-4-3-2-1. This occurrence halts the AID and causes the following series of information areas to be printed on the printer:

1. Registers (A-L,IX,IY), stack pointer, and program counter
2. Computer stack
3. Data link variables and buffers
4. ATARS display variables
5. ATARS tracker variables
6. ATARS debug RAM (defined above)

From some or all of this data, the problem can hopefully be analyzed and corrected. If some of the data is not required, pressing the NO key will skip the printing to the next item in the series. Also, if NO is pressed during the printing of the ATARS debug RAM, the system will be restarted.

9.0 ATARS ONBOARD SOFTWARE

This chapter outlines the algorithms and procedures that constitute the message processing and display creation routines, the two major components of the ATARS onboard processing system. The overall system, including a description of the context within which these routines fit, was presented in Chapter 7. As stated there, the level of detail to be provided is such that all the complex and unusual considerations that must be addressed are covered. Conversely, no attempt will be made to fully describe the obvious implementation details of the straightforward segments of the code.

The function of the message processing software is to combine the new information contained in the current scan COMM-A messages and the prior scans' information stored in the various internal files into a display buffer that describes the total status of the current ATARS scenario. This function should be nearly identical for all sophisticated avionics. Thus, if programmed carefully, it could support a wide range of display devices, and even permit "plug-in" attachment of new technology displays as they become available. In order for this simplification to be possible, the message processing routine must be the entity that recognizes and overcomes the effects of any and all possible errors or low probability events in the ground or air segments of ATARS. Then all complex debug operations can be performed once in great detail and be dispensed with.

The display creation routine is responsible for translating the ATARS scenario described in the display buffer into a visual picture (and/or aural message) for the pilot. Almost by definition this routine must be tailored to the specific display device. However, various segments of the code will be similar, independent of the device. Thus, by presenting the software details for the AID display, some guidance may be provided to designers of other display systems.

9.1 Message Processing Software

If the ATARS ground system and airlink always performed perfectly, the onboard message processing system would be extremely simple. Unfortunately, the following complications can be expected to occur from time to time:

1. Two (or more) sensors send ATARS messages to the aircraft at the same time.

2. Some messages may not be delivered due to channel time constraints for this aircraft.

3. Missed downlink acknowledgements result in duplicate messages being sent.

The second and third of these are not too difficult to overcome. The second forces code to be created to start, coast, and end encounters in the absence of the proper uplink messages; the third requires all messages to be compared with previously received ones.

The first complication, however, leads to the need for several sections of complex software. First, the two sensors may well employ different track numbers for the same encounter. This also implies that the same track number can be used for two different encounters (one by each sensor). Thus, a full track-to-encounter cross reference scheme is required. Second, the messages from the two sensors may arrive during the same time period, causing the onboard system to believe they have all arrived from one sensor. The algorithms must be on the lookout for this condition, as otherwise numerous false encounters may be created and displayed. Finally, the two sensors may disagree on the most critical encounter: since two most critical encounters would interfere with proper display behavior, arbitration software is required.

Figure 54 is a flowchart of the major modules in the onboard message processing system. The remainder of this section describes each box in detail. It is important to note again that the display buffer that is produced as the system output, whose format was shown in Figures 33 and 34, can be employed as the input of a very wide range of display devices. Thus, it is possible for a single microcomputer system, coded as described herein, to serve as a fixed part of any onboard system. As cheaper or better display avionics are developed, a simple replacement of only that one part need be effected.

9.1.1 Preliminary Processing

ATARS message processing can proceed only when all messages for a scan have been received. This group processing mode is required for two reasons: (1) ATARS messages are not independent, as in various situations the information for an encounter will be contained in two messages, and (2) the order in which the messages are processed can affect the results. An example of the second situation is that proper message-to-encounter correlation requires that messages with track numbers (such as threat or single prox) be considered before those without track numbers (such as dual prox).

The group of ATARS messages processed together is called a packet. As described earlier in Section 7.2, a packet is ended whenever a 100 millisecond interval occurs after receipt of the previous COMM-A messsage. This time is longer than the aircraft dwell time of any currently envisioned sensor antenna, and thus its having elapsed insures that no more messages are forthcoming this scan. However, if two sensors are transmitting ATARS advisories to the aircraft, and their dwell times overlap (or come within 100 milliseconds of each other), the two groups of messages will both be included in the same packet. The current software attempts to detect this occurrence by counting the number of most critical position messages contained within the packet. Since a sensor is permitted to mark only one such message per scan as

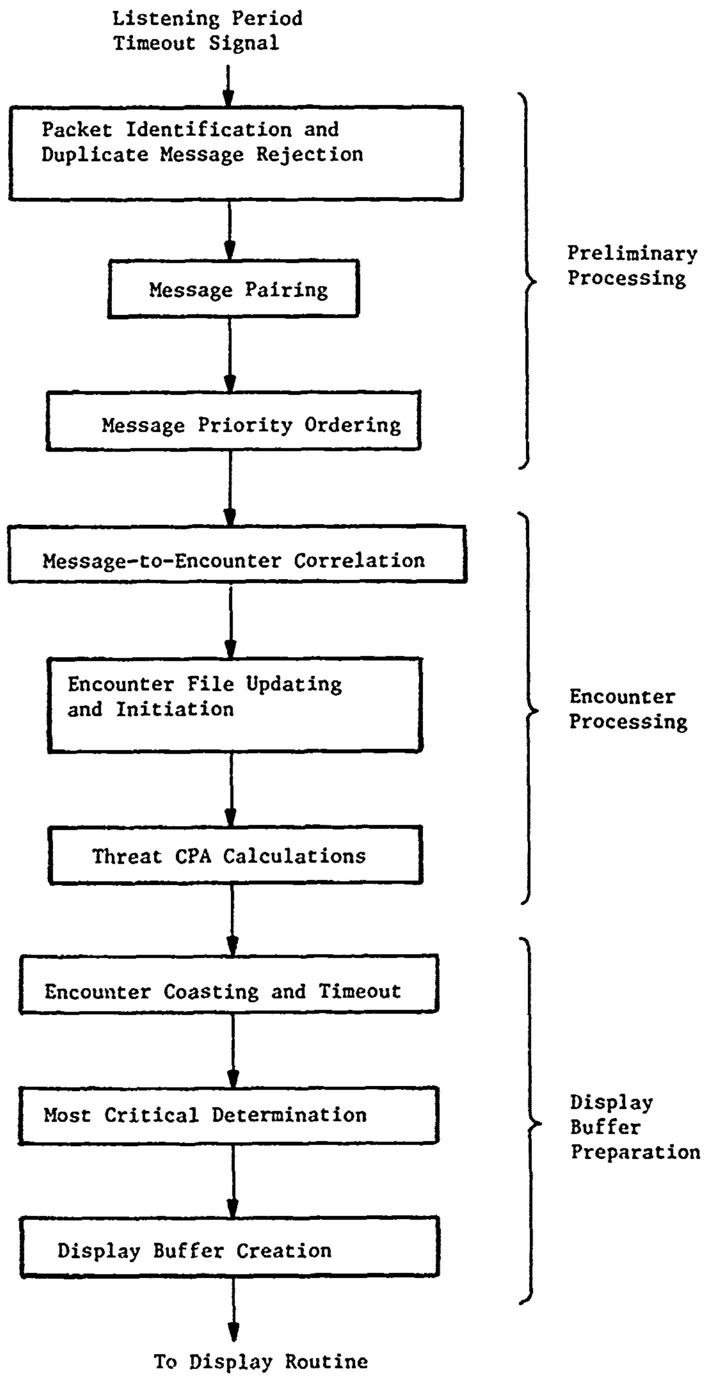


Fig. 54. Message Processing Modules.

most critical, a multiple count is taken as proof of an overlap. When sensor ID's exist, the actual separation of overlapping packets will become possible.

The preliminary processing routine is awakened when the 100 millisecond timeout signal is triggered. The processing initiation is delayed, however, if other tasks are still in execution. Thus, it is possible that messages from the next packet will have arrived by the time the processing begins, particularly if multiple sensors are uplinking information. However, only messages for the first packet are processed in the first program pass; the subsequent packet, if completely received by the end of this pass, is then processed immediately in a second pass through the software. Only then is control returned to other tasks. In particular, no display will be generated until both packets have been processed. This guarantees that the most current display will be shown as quickly as possible.

Once all messages in the packet are identified, a search is made for duplicate messages by a simple pairwise comparison. The number of most critical position messages remaining is then counted; if greater than one, overlapped data from two sensors has probably occurred and correlation must be more complex, as described below.

The next step is to pair messages when two exist for the same encounter. Two types of pairings are possible:

1. A start threat message with a threat message whose first time threat bit is set - the messages will have the same track number.

2. A half of a dual prox message having its most critical bit set with the supplementary part of an own plus supplementary message - each must be unique within the packet.

The final part of preliminary processing is sorting the ATARS messages into 5 classes of priority, ordered as follows:

1. own messages
2. threat messages
3. single proximity messages (and dual/supplementary pairs)
4. dual proximity messages
5. resolution messages

Own messages have highest priority because the current own aircraft heading and turn rate are needed for correlation of other messages to their corresponding encounters. Threat messages, being more critical than proximity ones, are treated next to provide a higher likelihood of proper correlation. Since dual proximity messages contain no track numbers to use for correlation, it is important that they be processed after all encounter

messages with track numbers; only then will the set of "leftover encounters" be known. Finally, resolution messages are totally independent of all others, and can be processed at any time.

9.1.2 Encounter Processing

The encounter processing routine is responsible for updating the position and status of all active encounters. It performs this mission in three parts. First it correlates the newly received ATARS messages with the encounters existing from the previous scan. Then, whenever a failure results, a new encounter file is opened. Finally, it updates the information in each encounter file from the fields of the new messages. In addition, if any threat encounters exist, it computes the closest point of approach data for them.

The correlation procedure complexity depends upon whether or not the onboard computer believes ATARS to be in its "normal" condition, which is that messages are being transmitted by a single sensor. The set of checks that must be satisfied for normality to hold when no sensor ID's exist is:

1. The last three own messages have their seam bit set to zero (indicating single coverage).

2. Only one most critical message exists in the current packet.

3. No encounter is being updated by two or more track numbers.

4. No track number is being used to update two or more encounters.

The first condition would be sufficient if perfect ground coordination could be assumed. The third and fourth conditions could be caused by previous onboard correlation errors as well as by multiple coverage; whatever the cause, however, more complex correlation logic would be needed.

Figure 55 presents the overall correlation flowchart. The usual correlation mechanism between ATARS message and encounter file is the ground-assigned track number. Thus, if no number exists, such as for a dual proximity message, a more complex comparison of position attributes between message and encounter file must be undertaken. The description of this matching process is presented below.

Normally, only encounters not yet updated by a message in the current packet are permitted to enter into such correlation processes. However, if messages from two or more sensors are thought to be contained in this packet, as signalled by more than one message with its most critical bit set, this rule must be waived; each encounter may then be updated once by each sensor. Sensor ID bits would be very useful in these situations to prevent an encounter from being erroneously updated by two messages from one sensor, instead of by one from each.

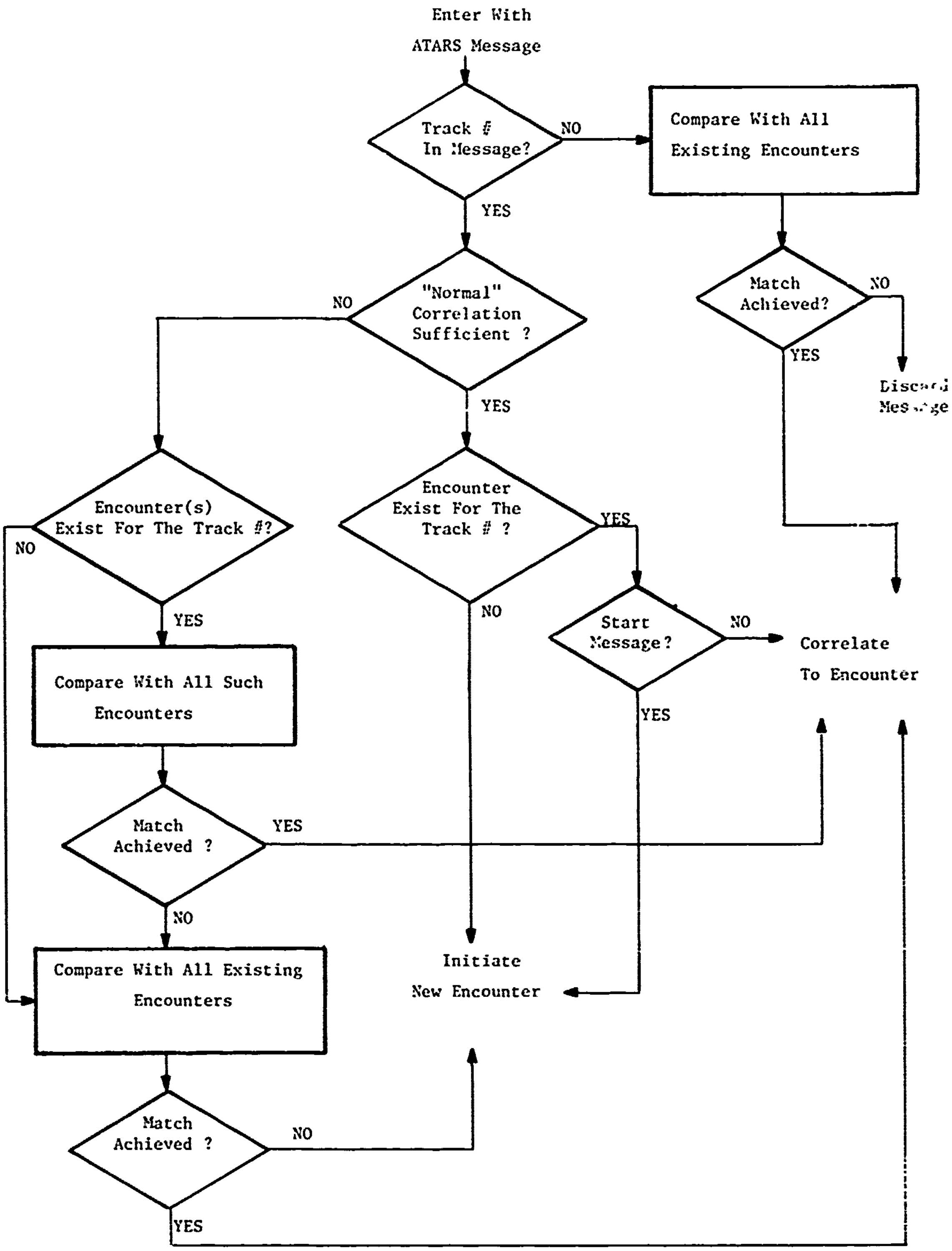


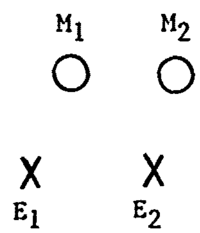
Fig. 55. Message-to-Encounter Correlation Flowchart.

Should a match be discovered, the dual proximity message is assigned to that encounter. No attempt to find the "best" match is made should two encounters be acceptable, as the data quality is too poor to support a complex scoring mechanism; instead, the search ends with the first match. No serious harm could result from an improper cross correlation. In the worst case, depicted in Fig. 56, an extra proximity will appear on the screen for one scan.

If no match is discovered for the dual proximity message, it is discarded, as no new encounter can be initiated without a track number. As long as proximity start messages with their track numbers are repeated each scan until a downlink acknowledgement is received, as is assumed, the condition of uncorrelated dual proximity messages should not arise. Even if it does, the loss of the encounter cannot be critical: should the encounter transition to a threat status, the threat messages transmitted for it will contain a track number, and the encounter file will then be opened.

When the ATARS message contains a track number, such as threat or single proximity messages, and the ATARS system is in its "normal" state as defined above, the message to encounter correlation is obtained directly from the cross reference array entry. If this entry is null, a new encounter file is opened, while if it contains an encounter number, that file is the one to update. One complication arises when an entry exists but the ATARS message indicates the start of a new encounter. This situation arises, as discussed in section 4.3, when the ground sensor had more than eight encounters and thus does not have track numbers available for all of them. In such a case, a new encounter may be assigned a number previously assigned to another one without that latter one being terminated by an end message. Thus, the proper onboard action when this situation is encountered, as shown in the flowchart, is to initiate a new encounter file. The old one, when not updated, will be dropped.

Should ATARS not be in a normal state, however, no correlation can be accepted without the comparison of position attributes described below. This is because a track number can be used for different encounters by different sensors. Should one or more encounter currently exist for the track number, as shown by the cross reference array, one of these will probably be the proper one. Thus, these encounters are tested first for a match condition. If all such encounters fail the test, or if no encounters were listed for the track number, every existing encounter is tested for a successful match. If still only failure results, a new encounter file is initiated. As for the dual proximity case, the first successful match is accepted, as no method for choosing between matches could be supported by the quality of data in the ATARS message. This could conceivably result in a wrong correlation, although the existence of track numbers in the messages makes this an extremely remote chance.



Correct Actions are:

Message M_1 updates Encounter E_1
Message M_2 updates Encounter E_2

However, with "first success" rule, if M_1 first attempts to correlate with E_2, the results will be:

Message M_1 correlates with and updates Encounter E_2
Message M_2 fails to correlate with Encounter E_1 and thus initiates new Encounter E_3
Encounter E_1 is coasted

and 3 proximities instead of 2 will appear on the screen this scan.

Fig. 56. Correlation Failure Example.

The matching algorithm employed for correlation checks three position attributes: relative altitude, range, and relative bearing. In each case, these quantities in the encounter file are projected forward one scan, using the encounter file rates, to the current time, and then compared with the corresponding quantities in the new ATARS message. Two boxes are defined around each projected position attribute, a small one and a large one. If the message quantity falls within the smaller box, the correlation score (which starts at 0) is not changed; if within the larger box, the score is incremented by 1; if outside both boxes, the correlation is rejected. A match is said to have occurred if no attribute results in rejection and the final score is no greater than 2. This implies that a tight match on at least one attribute, and reasonable matches on the others, is required for correlation.

Four special situations must be considered in this matching algorithm. First, if the encounter is a new one, the encounter file rates will not yet exist. In this case, the own turn rate provides the best guess as to the bearing rate, being its main component, and the encounter's vertical speed (if known) provides an estimate of the altitude rate. Since no such range rate estimate exists, the predicted range must be set equal to the current range for new encounters. Second, because this resulting predicted position is less accurate for new encounters, the correlation boxes must be made larger for them. Third, although the bearing boxes are generally defined in degrees, they cannot be allowed to shrink smaller in miles than the range boxes for close-in encounters.

Finally, both larger altitude boxes and special case recognition is required for encounters beyond 2000' in relative altitude. The former reflects the coarser level of altitude specification (namely 500' lsb) in this area, while the latter reflects the fact that either the message or the encounter file may be missing the altitude extension field. Thus a relative altitude of 2000' in either the message or the file must be considered as matching any larger value in the other.

Once the correlating encounter for the new ATARS message is determined, any alterations to the cross reference array (depicted in Figure 32) that this match necessitates are made. The following are the cases requiring some action:

1. The message was an end message - the cross reference entry is removed; if the encounter is no longer supported by any track number, it is dropped.

2. The message track number is a new one for the encounter - a new cross reference entry is created, and the encounter is now supported by an additional track number.

3. A new encounter was initiated - the new cross reference entry is created.

In the normal single sensor environment, an end message causes the encounter to be dropped, and no encounter will ever be supported by two track numbers.

The updating of the various ATARS files from the new scan's messages is fairly straightforward. The descriptions of the fields in these files provided in section 7.3 indicated the manner in which each is determined. Thus, only a few more notes are warranted in this section.

If an own or resolution message is present, the own file is updated prior to the above correlation actions. This permits the most current own data to be employed in the correlation tests. When all message-to-encounter correlations are completed, each active encounter file is brought up to date by any message or messages correlated to it. Then messages for which no encounter files previously existed are used to create new encounter files.

For each threat encounter, a check is made to determine whether the closest point of approach calculations described in the Appendix can be made. The three conditions that must be satisfied for these equations to be relevant are:

1. the encounter is not newly initiated on the current scan - if so, no positional rates will yet exist

2. the current range is greater than the miss distance - if not, the data is not consistent

3. the relative range rate of the aircraft is negative - if not, the calculated quantities will be meaningless.

9.1.3 Display Buffer Preparation

Once all the ATARS files have been updated, the total current ATARS scenario can be constructed. The display buffer, whose format was described in Figures 33 and 34, is the vehicle used to transmit this snapshot to the display drawing software. As part of this buffer preparation process, two auxiliary functions are performed. The first is the elimination of timed-out encounters, namely those not updated by the ground for two successive scans. The second is the verification of the most critical encounter logic. As explained in section 7.3, several anomalous events can cause no or several encounters being so labelled instead of the mandated single one.

The positions of encounters not updated on the current scan must be coasted before being entered into the display buffer. If the encounter has been updated at least once since its initiation, the range, bearing, and altitude rates to apply are resident in the encounter file. Otherwise, the latter two rates can only be inferred in a gross sense, while no range rate estimate at all can be made. The largest bearing change component is due to own aircraft turns. Since own turn rate is known, this correction component can be computed for new encounters. Similarly, the vertical speed of the other aircraft, if provided, can be used to update the estimate of the current altitude difference.

The time interval for a coast action is the difference between the current time and the last update time stored in the encounter file. If this interval exceeds 1 1/2 scans, the encounter is dropped and not entered into the display buffer. The encounter cross reference array is then adjusted to reflect this loss.

After the status of each encounter has been updated, a count is made of the number labelled most critical. Depending upon the result, one of the paths presented in the flowchart of Figure 57 is logically followed. Only the path for a result of one represents proper behavior.

However, as shown in the flowchart, even with this result an anomaly could have occurred. In particular, if the most critical encounter is a proximity, and yet a threat encounter exists, the outcome is inconsistent. If the threat was not updated on the current scan, then the only logical conclusion (assuming no ground error) is that the encounter had transitioned to proximity status (or even disappeared) and the uplink message confirming the event was not received. Thus, the onboard processor will be acting properly by converting the encounter out of threat status as shown in the flowchart. If the threat encounter was updated, though, an unexplainable situation exists. The best the onboard processor can do in this case is to set the most time-critical threat to be the most critical encounter, and remove that label from the proximity.

Whenever none or several most critical encounters exist, the onboard processor must select one encounter to be so labelled for the display. To aid in this decision process, the encounter set is partitioned into the eight possible subsets corresponding to the states of three binary parameters: threat or proximity, updated or coasted, most critically labelled or not. Within each subset the most dangerous encounter is found, with time to CPA and range being the criteria for threat and proximity encounters respectively. The eight "winners" are then denoted as follows:

MCUT - most critical updated threat winner
MCCT - most critical coasted threat winner
MCUP - most critical updated proximity winner
MCCP - most critical coasted proximity winner
NCUT - non-critical updated threat winner
NCCT - non-critical coasted threat winner
NCUP - non-critical updated proximity winner
NCCP - non-critical coasted proximity winner

Of course, any of the subsets could be null, as would then be its winner.

If no most critical encounters exist, the first four subsets must be null, and so the encounter to be labelled most critical could only be one of the latter four winners. The most likely explanation for the absence of a most critical encounter is that its uplink message was not received. Thus, if a coasted threat exists, it may well have been the one set most critical by

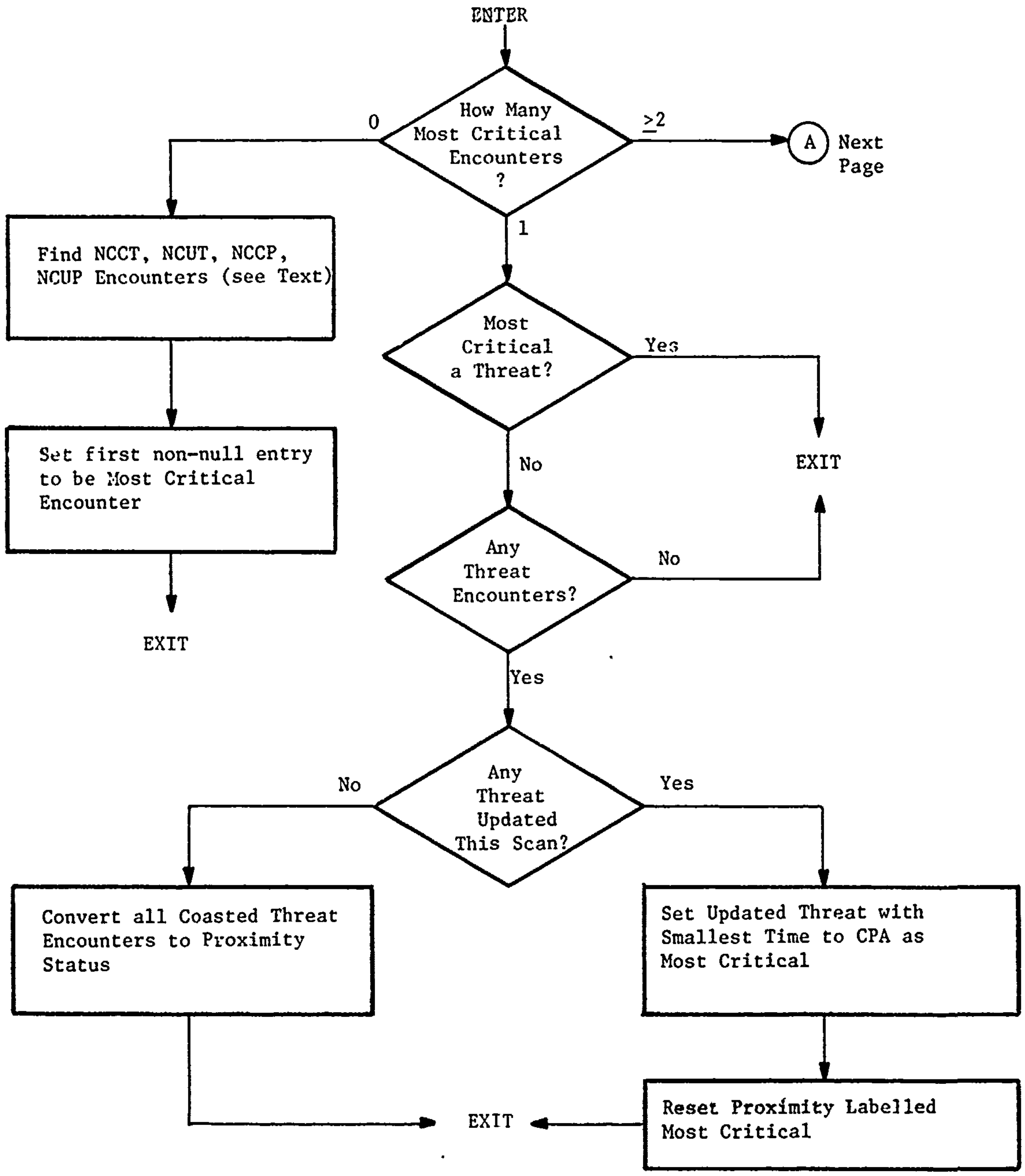


Fig. 57. Most Critical Encounter Logic (1 of 2).

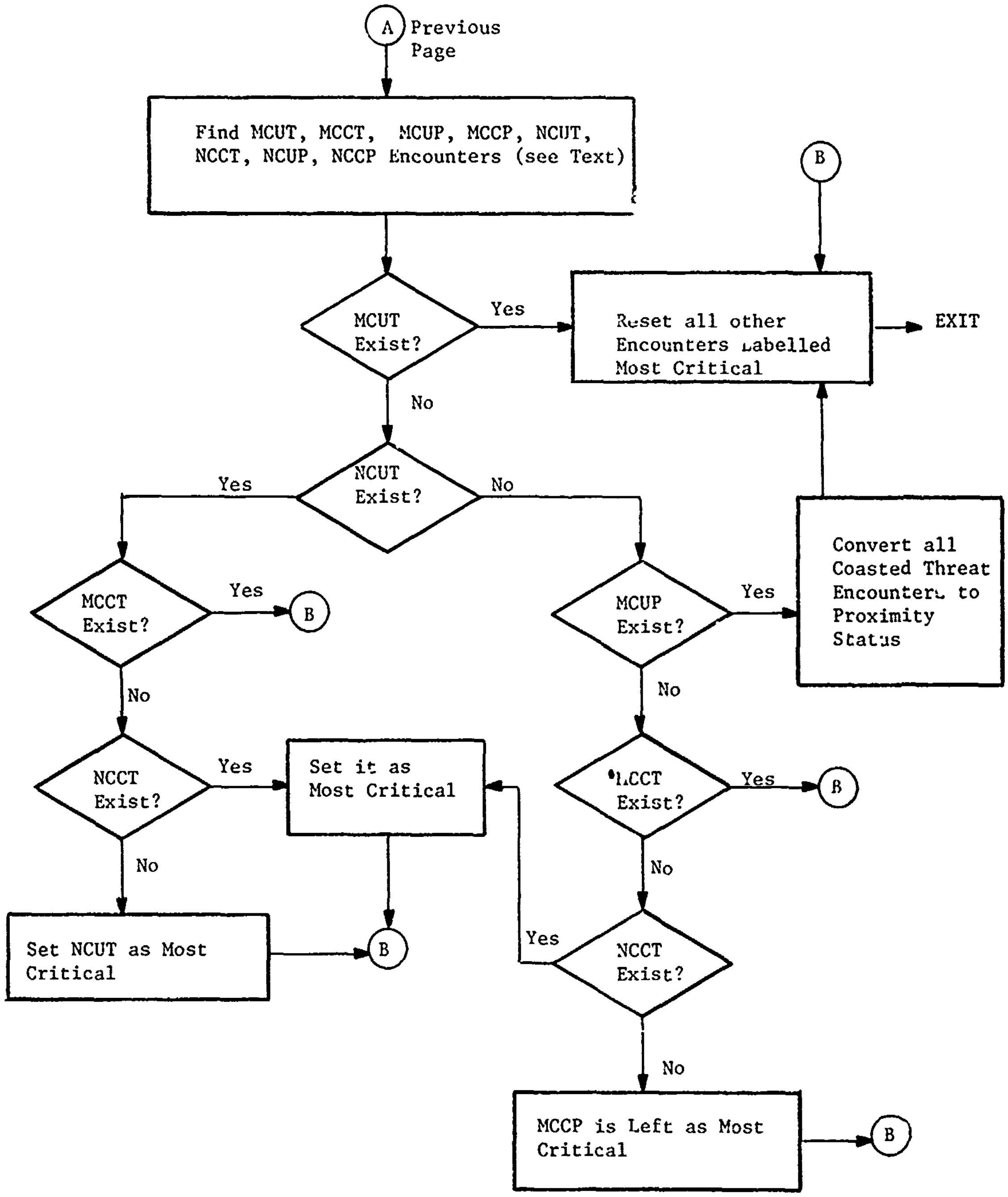


Fig. 57. Most Critical Encounter Logic (2 of 2).

the ground. This accounts for NCCT being the first choice if not null. Similarly, NCCP is chosen before NCUP if no threats exists. The only anomaly occurs if an updated threat and a coasted proximity, NCUT and NCCP, are in competition. Clearly, the ground could have converted this proximity to a threat and labelled it most critical. However, the decision was made at Lincoln not to "create" threat encounters in the onboard processor in the absence of information. Thus the known threat encounter NCUT is set most critical.

Finally, if several most critical encounters exist, any or all of the eight subsets could be populated, and hence the selection rules become more complex in this case. The details of the algorithm specifying the competition among the winners is given by the flowchart. Clearly, if a most critical updated threat exists, it must be selected. However, a non-critical updated threat will be beaten by either type of coasted threat according to the logic presented above. If no updated threat of either type exists, a most critical updated proximity takes precedence over a coasted threat. As discussed under the case of one most critical encounter, all such coasted threats are converted to proximity status by implication of the ground actions. Finally, the remainder of the selection process reflects the decision never to upgrade a proximity to a threat without ground notification.

Once these preliminaries are out of the way, the actual creation of the display buffer can commence. The manner in which each of its entry fields is filled from the encounter files follows from the discussion of section 7.3 and so no further details will be provided here.

The display buffer header fields come from the own file, from the screen parameter values as set by the operator, and from an active encounter count maintained by the buffer creation code. Two special actions are required during the header formation. First, a check must be made whenever a resolution advisory exists as to its last update time. If 16 or more seconds have elapsed, the advisory has timed out, and it must be removed from the display. This action is performed by zeroing the resolution fields and setting the first time resolution bit to signal the state change. The other special action is setting the 3-second bit of the header whenver less than 3 seconds have elapsed since the last display buffer was presented to the display. Many displays, including the AID, can not be updated faster than every 3 seconds without compromising pilot comprehension.

9.2 Display Creation Software

The display creation software, in comparison with the code just described, is fairly straightforward and free of special cases. Its only input is a display buffer with a guaranteed format, and thus it is insulated from any errors or unusual cases produced by the ground or airlink parts of the ATARS system. A flowchart of this routine is provided by Figure 58.

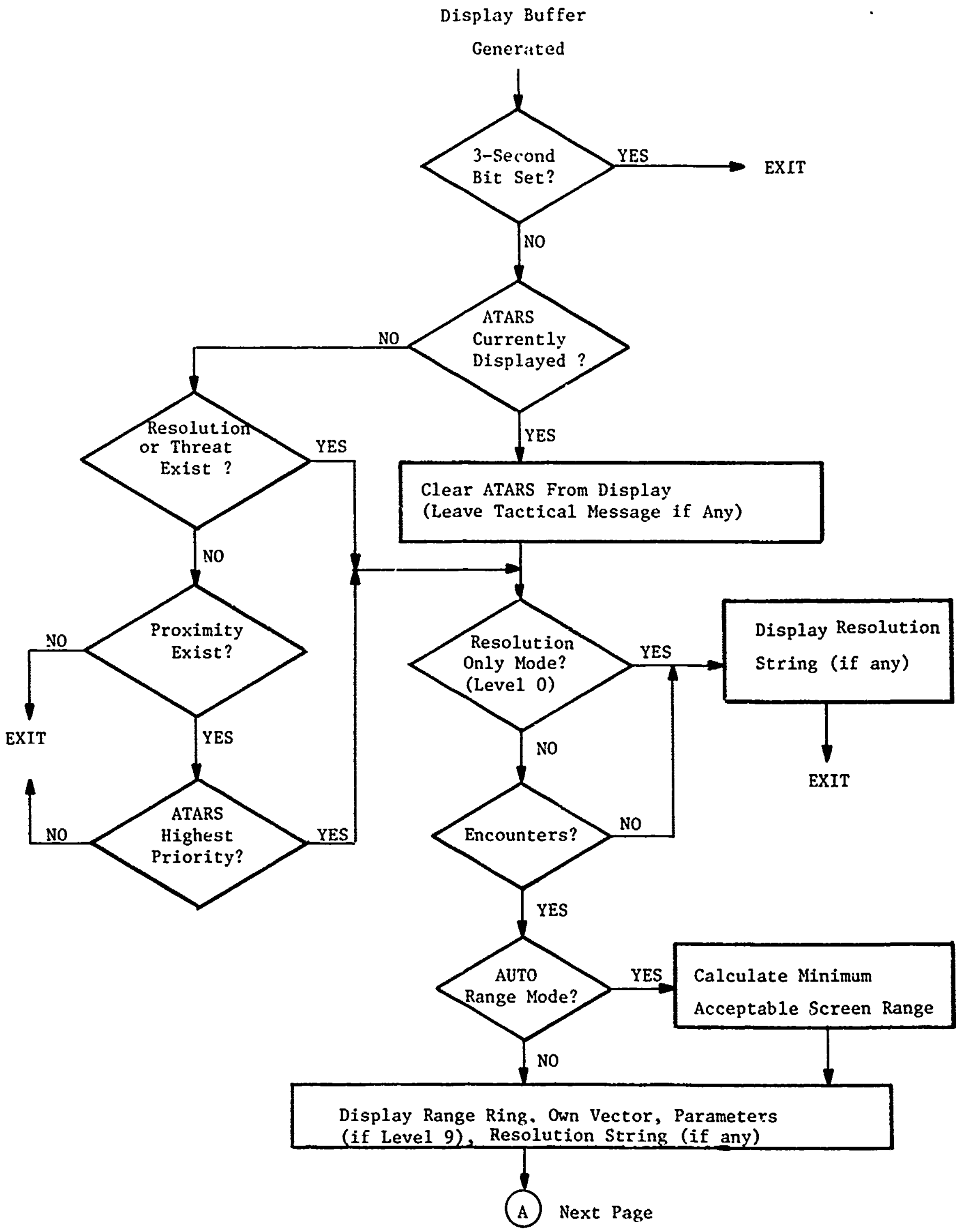


Fig. 58. Display Creation Logic (1 of 2).

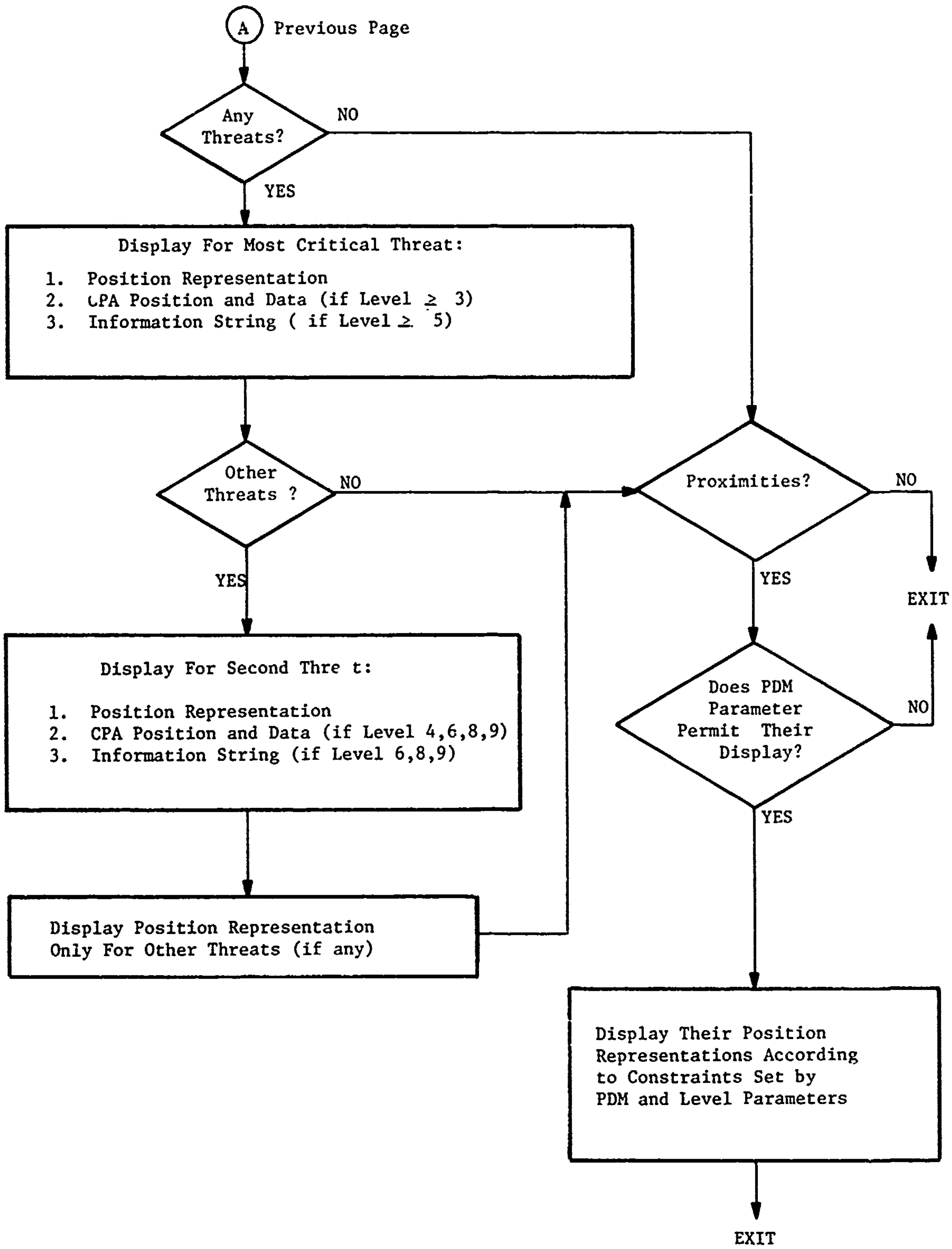


Fig. 58. Display Creation Logic (2 of 2).

If the new display buffer is less than 3 seconds more current than the existing ATARS display, it is discarded and the present picture left on the screen. This rule provides the pilot with sufficient time to absorb a display before it is replaced. Otherwise, if ATARS is on the screen, its display area is cleared in preparation for the construction of the new scan's display. Any tactical message residing at the top of the display (see Figure 27) is kept, however.

If ATARS is not currently being displayed, a determination must be made as to whether its priority is sufficiently high to replace the current screen user (data link, weather) if any. If the ATARS scenario includes a resolution or threat advisory, it is automatically the highest priority user. Otherwise, if only proximities exist, the priority set by the proximity priority parameter determines the screen use. Section 7.2 discussed this issue in detail. Finally, if no ATARS advisory of any type exists, no ATARS display is generated.

Two types of ATARS displays have been defined. If the screen level parameter is set to 0, only a resolution string is desired. With any other level setting, a graphical picture in addition is sought. With no encounters present, of course, the latter type degenerates to the former one.

The first action that must be performed when a graphic display is desired is the determination of the screen range setting. If the RNG parameter is in a manual mode (refer to section 8.2.1), its value specifies the range setting. Otherwise, the display software must calculate the proper value from the locations of the encounters included within the guaranteed to be on screen subset (all, threats, or most critical). The procedure is to process each such encounter as follows:

1. read its bearing;

2. compute the screen expansion factor for that bearing (such as 1.0 at 90°, 2.0 at 0°, 1.4 at 135°, or 2.2 at 45°) due to the rectangular shape of the display region;

3. divide its range by this factor.

The proper screen range setting is then the largest value found in any encounter's step 3, rounded up to an integer, with a minimum setting of 2 miles.

Once the screen scale factor is known, the fixed parts of the display can be generated. These are the two mile range ring, the own aircraft vector, the parameter values if the level parameter is 9, and the resolution string, if any. Three lines are reserved for resolution advisories. The only time that this value is insufficient is if two positive/negative resolutions and a vertical speed limit resolution all exist at once, such as:

NO RGT	(don't turn right)
NO LFT	(don't turn left)
LM CLI 1000	(limit climb to 1000' per minute)

In this case, the fourth line will not appear. Its importance, though, is much less than any of the other three.

The remainder of the display code generates the presentation of the information for the active encounter set. Whenever one or more threat exists, the first encounter processed is the most critical threat, identified by having its most critical bit set. First its position symbol, heading vector, and altitude alphanumerics are drawn at its relative location. Then, if the level parameter is set to 3 or greater, the closest point of approach and relative motion line details are drawn.

The relative motion line extends from the current position symbol to the CPA position X. This line is drawn dot by dot on the screen along the calculated slope. Each time 10 seconds worth of dots have been drawn, a perpendicular tick mark is constructed. These marks are skipped, however, if the current position is off-screen. A line is still drawn from the triangle position symbol to the X, even though its slope will not be quite correct. This effect is illustrated by Figure 59.

Since the time to CPA is written in a sidebar area, one of the two possible sidebar areas must be chosen. The rules specifying this selection are:

1. if the time to CPA was shown last scan, use the same side again

2. if this is the first presentation of time to CPA, choose the side nearer the position of the threat

The first rule allows the pilot to concentrate on the time to CPA values as they proceed through their time sequence without having to jump his viewpoint from side to side. The aircraft information data, if applicable to the level, is written in the same sidebar.

Other threats, if any, are processed next. Each has its position symbol, heading vector, and altitude alphanumerics drawn provided the location is within the screen boundaries. If not, a triangle is drawn on the screen boundary at the proper bearing. In addition, if the level parameter is set to 4,6,8 or 9, the closest approach position and associated data is drawn for the second threat. No algorithm is provided for selecting this second threat when more than two threats exist; the one earliest in the display buffer wins. This random selection rule is justified simply by the expectation that three threats will probably never occur at once. The second threat time to CPA, and aircraft information if necessary, are placed in the remaining sidebar area of the display.

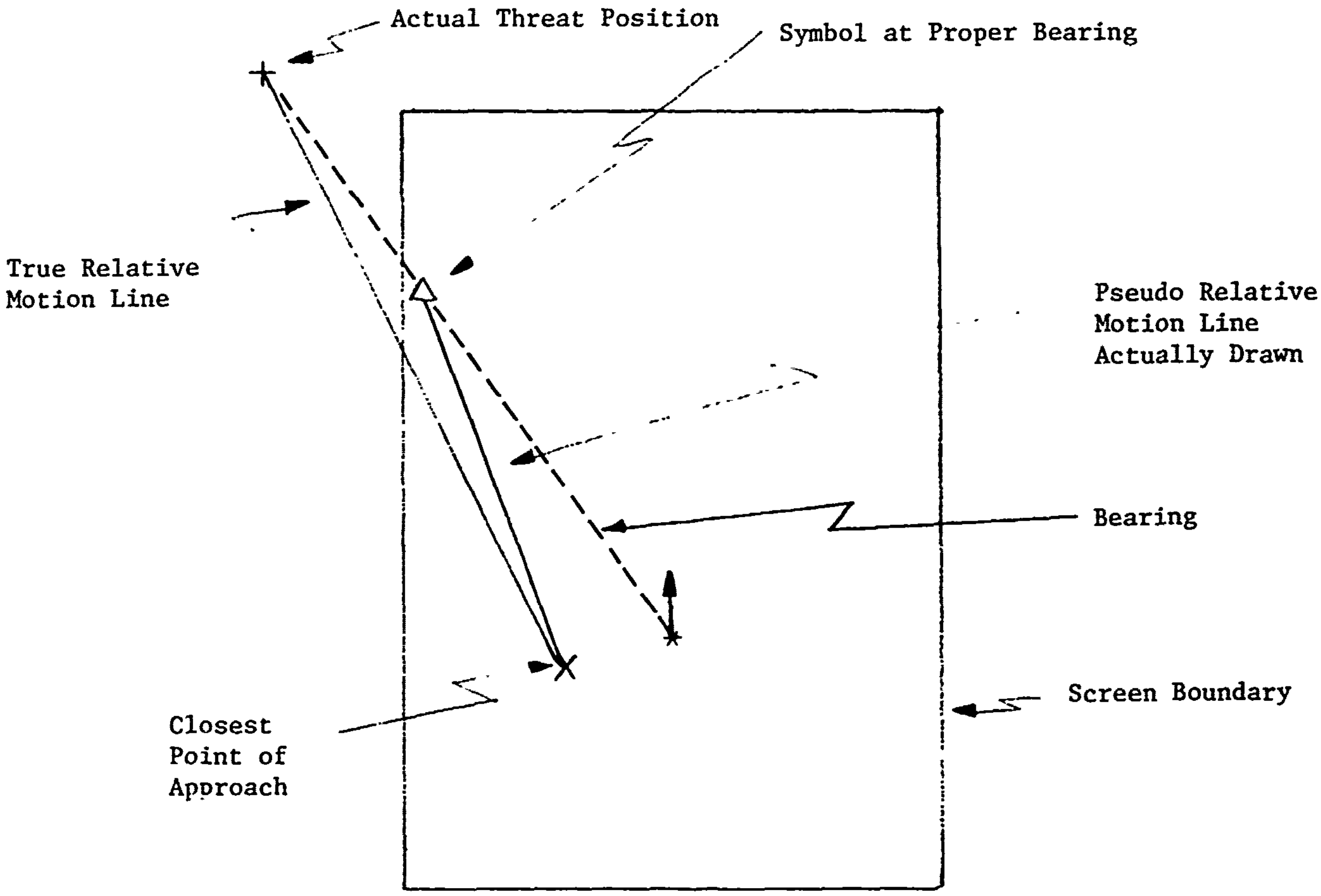


Fig. 59. Relative Motion Line for Off-Screen Threats.

Finally the proximity encounters, if any, are processed. If no threats exist, and the proximity display mode is "point/none", no representation of proximity encounters is desired. Otherwise, either a full symbol plus vector plus alphanumeric format, or a point symbol format, is provided for each. Again, only a triangle is drawn for any off-screen encounter. Also, any encounter just within the screen boundary, but whose heading vector extends beyond it, is drawn without this vector. Its absence at least informs the pilot of the encounter's positive range rate.

APPENDIX

ATARS Closest Point of Approach (CPA) Calculations

Overview

The full information display of the Lincoln designed ATARS onboard system specifies the parameters of a threat encounter in the manner depicted in Fig. A1. The heart of this picture is the relative motion vector from the threat aircraft's current position to its predicted closest point of approach. The time until this near-miss point is attained is also specified, both as tick marks on the vector and as a number on the side of the screen.

The current version of the ATARS message formats does not provide all the information needed to create this display. In particular, of the four quantities needed for the picture shown in Fig. A1:

1. Miss distance
2. Miss bearing
3. Miss altitude
4. Time to closest approach

only the first is supplied by the ground sensor. Thus, the latter three must be computed in the onboard computer.

In order not to overtax the microcomputer in the onboard ATARS system, the calculations of these quantities must be fairly simple, and not contain complex mathematical functions (such as square root). This appendix develops formulas that meet this restriction.

This appendix also investigates the effect of the truncated data accuracy in the uplink messages on the time of closest approach calculation. As this quantity is most sensitive to data variations, the equation, although exact, could yield an erroneous result when computed onboard. Of course, the ground tracker itself could have computed incorrect data values, particularly aircraft headings. The effects of these errors on the time to closest approach is also studied.

Exact Formulas

The underlying geometry for the closest approach calculations is presented in Fig. A2. The known quantities, from uplink messages, are the following:

1. Current range to threat, ρ
2. Current relative bearing of threat, β
3. Current relative heading of threat, h
4. Current velocity of threat, v

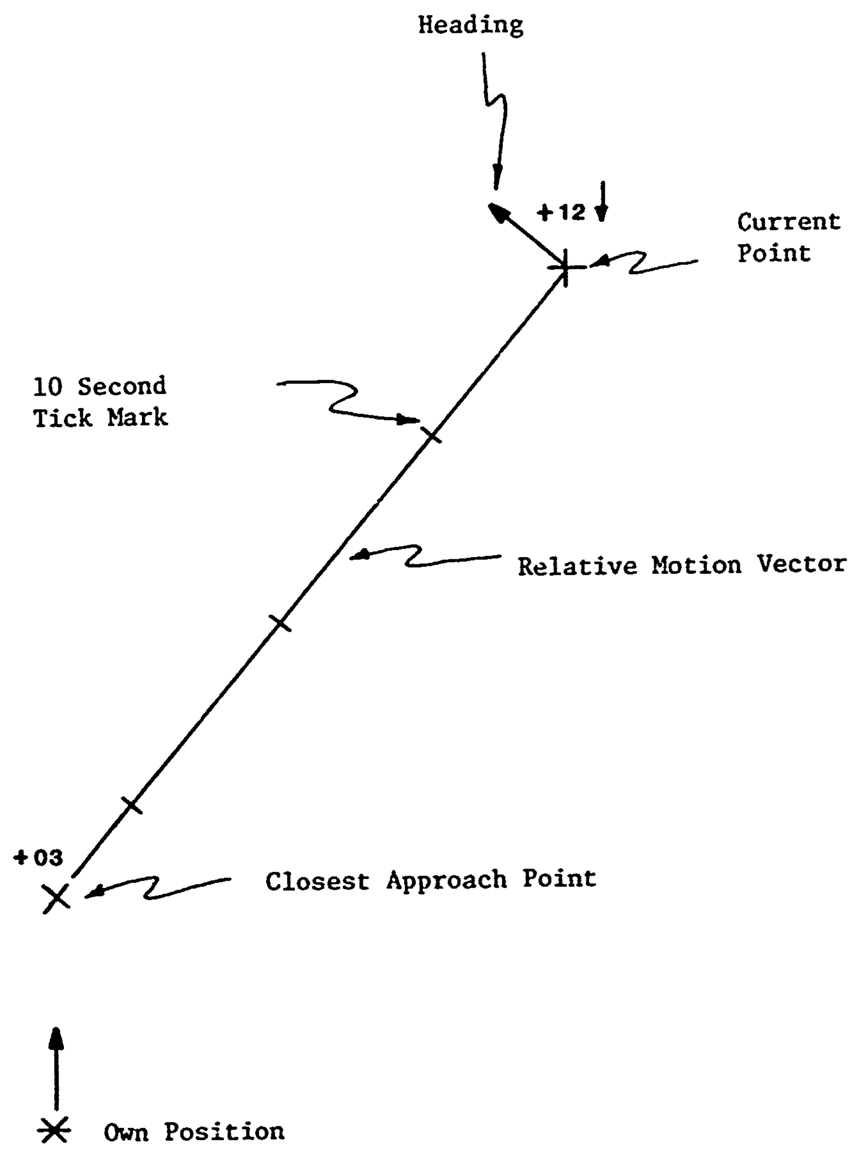


Fig. A1. ATARS Threat Display.

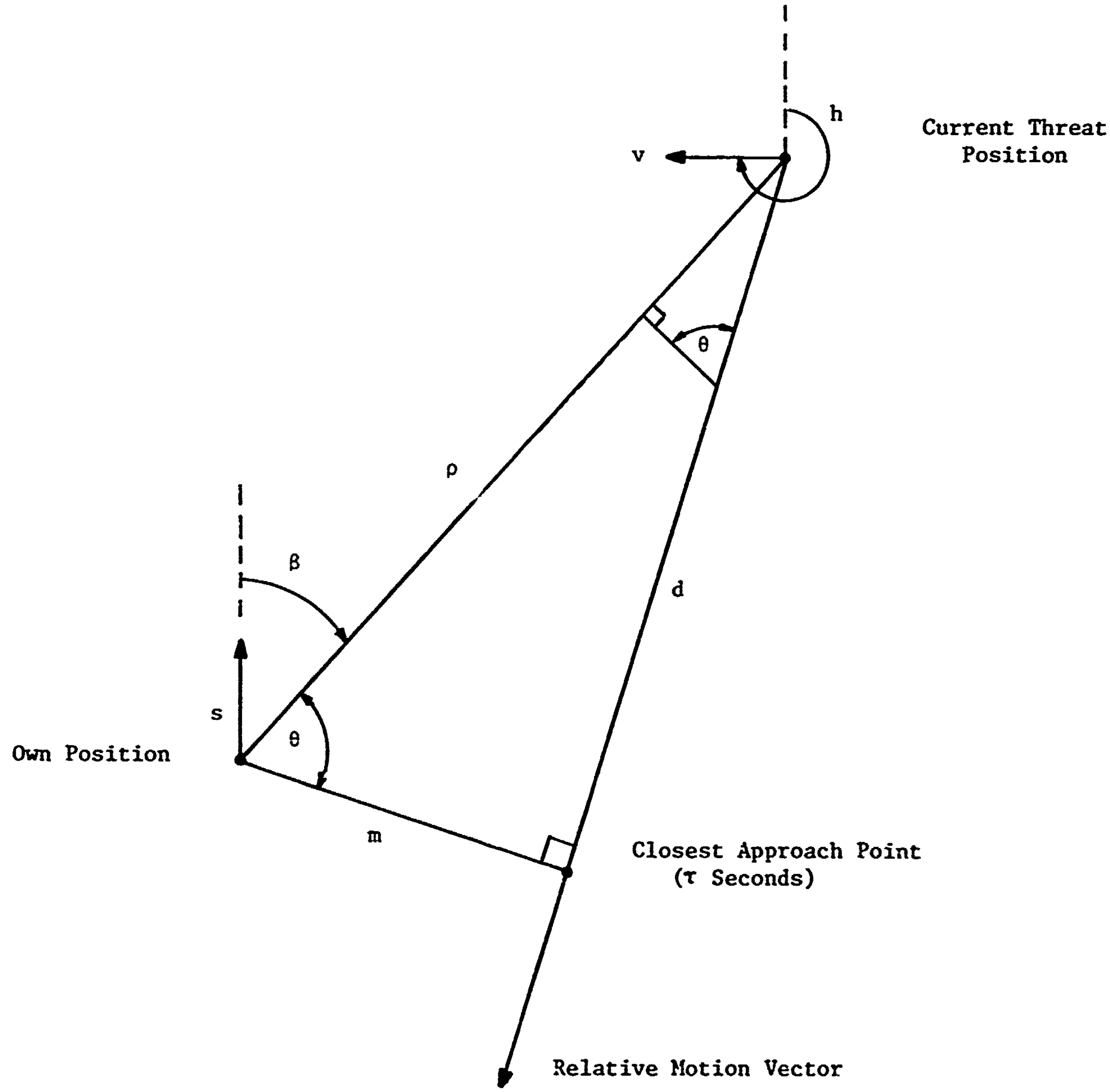


Fig. A2. Closest Approach Geometry.

5. Current relative altitude of threat, z
6. Altitude rate of threat, z_t
7. Current own speed, s
8. Current own heading, h_o
9. Predicted miss distance, m

Also, it is assumed that onboard instruments tied into ATARS can provide the own altitude rate, z_o.

Since the miss distance must be perpendicular to the relative motion line, the angle θ, which is the difference between the current and closest approach bearings (see Fig. A2), is given simply by:

$$\theta = \cos^{-1}(m/\rho) \tag{1}$$

However, since the miss point could be on either side of the current bearing, a determination must be made as to the sign of θ, i.e.:

$$\beta_m = \text{miss bearing} = \beta \pm \theta$$

This determination is made by computing the heading of the threat aircraft's relative motion vector:

$$h_{rel} = \tan^{-1} \frac{\text{relative x motion}}{\text{relative y motion}}$$

$$h_{rel} = \tan^{-1} \frac{v \sin h}{v \cos h - s} \tag{2}$$

Then, if the relative heading is to the "right" of the current bearing, θ is added, or if to the "left", θ is subtracted. Mathematically, this can be expressed by:

$$\text{if } (h_{rel} - \beta) \leq 180°, \text{ use } + \theta$$
$$\text{if } (h_{rel} - \beta) > 180°, \text{ use } - \theta \qquad (2')$$

where continuous subtraction at 360° is required

(i.e.: 150° - 350° = 160°).

The most direct formula for the time until closest approach is given by the ratio of the distance along the relative motion line and the velocity along this line, which is of course the relative velocity of the threat aircraft. Thus, referring to Fig. A2:

$$\tau = \frac{d}{v_{rel}}$$

$$\tau = \frac{\rho \sin \theta}{\sqrt{(v \sin h)^2 + (v \cos h - s)^2}} \qquad (3)$$

Finally, once τ is known, the relative altitude of the threat aircraft at the closest point of approach is given simply as:

$$z_m = z + (\dot{z}_t - \dot{z}_o)\,\tau \qquad (4)$$

Simplified Formulas

The previous section has demonstrated that an onboard computer has sufficient information to compute all required closest approach quantities. However, to do so it must be capable of performing all the mathematical functions contained in equations (1) - (4), namely arccosine, arctangent, sine, cosine, and square root. Most microcomputers are incapable of this level of mathematical sophistication unless a table lookup procedure were employed. Even with this approach, the arctangent and square root calculations would be quite complex and time consuming.

By only requiring the calculation of a threat's closest point of approach on the second and subsequent scans of an encounter (implies first threat scan is permissable for an encounter beginning as a proximity), a decided simplification of the mathematics results. With two or more scans of data available, the bearing, range, and altitude rates of the threat aircraft can be computed:

$$\dot{\beta} = \frac{[\text{new } \beta - \beta \text{ (n scans ago)}] + [\text{new } h_o - h_o \text{ (n scans ago)}]}{n * \text{scan rate}}$$

where second term removes effects of own turn

$$\dot{\rho} = \frac{\text{new } \rho - \rho \text{ (n scans ago)}}{n * \text{scan rate}}$$

$$\dot{z} = \frac{\text{new } z - z\text{(n scans ago)}}{n * \text{scan rate}}$$

The value of n should be small, to detect changes in aircraft headings or climbs, yet large enough to allow some averaging; probably n = 2 is best. Of course only n = 1 is possible for the second scan of an encounter.

Once $\dot{\beta}$ is known, its sign provides the direction of movement of the threat aircraft, and hence the direction of the closest bearing point relative to the current one (under the usual linear motion assumption). Thus, (2) and (2') can be replaced by:

$$\begin{aligned} &\text{if } \dot{\beta} > 0,\ \beta_m = \beta + \theta \\ &\text{if } \dot{\beta} < 0,\ \beta_m = \beta - \theta \end{aligned} \qquad (5)$$

and the difficult arctangent function is no longer required.

Similarly, by knowing $\dot{\rho}$, formula (3) can be simplified by relating the relative motion velocity to its projection along the current bearing line:

$$\dot{\rho} = v_{rel} \sin \theta$$

thereby reducing the result to:

$$\tau = \frac{d}{v_{rel}}$$

$$= \frac{\rho \sin \theta}{\dot{\rho}/\sin \theta}$$

$$\tau = \frac{\rho}{\dot{\rho}} \sin^2 \theta \qquad (6)$$

This removes the other complex function, the square root.

Finally, the value of $\dot{z}$ can be used directly to compute altitude at closest approach:

$$z_m = z + \dot{z}\,\tau \tag{7}$$

Thus, the assumption that own climb rate is supplied by a tie-in between onboard instruments and ATARS is no longer required.

Improved τ Formula

The rates computed in the previous section are all subject to large errors because of the data truncation employed by the uplink messages. Specifically, the least significant bits in the measurements are:

β: 3.75°
ρ: 0.2 miles
z: 100 feet

Thus, large fluctuations in scan to scan rates are to be expected. Furthermore, if any threat aircraft measurement changes sufficiently slowly, the same value will be reported on consecutive scans, leading to a computed zero rate.

Since only the sign of $\dot{\beta}$ is used in the β_m computations, fluctuations are irrelevant. Also, if a zero value is determined, the value of θ must be very small, so using addition or subtraction will make a minor difference, imperceivable on the display.

Similarly, any possible fluctuations in $\dot{z}$, especially with a two scan average, will have only a minor effect on the quality of the display. Again, a value of zero indicates a very small true value, so the displayed value of closest approach altitude will be reasonably accurate.

Unfortunately, fluctuations in $\dot{\rho}$ will cause serious variations in the value of τ from scan to scan, leading to lack of confidence in its displayed value by the pilot. Furthermore, if the closing rate of the threat aircraft is small enough to produce a $\dot{\rho}$ of zero, an infinite τ will be computed. Thus, an improved formula for τ is required.

The improved formula is based on the fact that the vector dot product is equivalent to the projection of one vector on the other. The relevant identity is this case is:

$$\vec{\rho} \cdot \vec{v}_{rel} = -\rho\dot{\rho}$$

Thus, formula (6) is converted to:

$$\tau = \frac{\rho}{\dot{\rho}} \sin^2 \theta$$

$$= \frac{-\rho^2}{\vec{\rho} \cdot \vec{v}_{rel}} \sin^2 \theta$$

$$= \frac{-\rho^2 \sin^2 \theta}{\rho\ (\sin \beta)\ v\ (\sin h) + \rho\ (\cos \beta)[v \cos h - s]}$$

$$\tau = \frac{-\rho \sin^2 \theta}{v \cos (\beta - h) - s \cos \beta}$$

Finally, seeing from Fig. 2 that:

$$\sin \theta = \frac{d}{\rho} = \frac{\sqrt{\rho^2 - m^2}}{\rho}$$

the result can be expressed as:

$$\tau = \frac{(\rho^2 - m^2)}{\rho[s \cos \beta - v \cos (\beta - h)]} \tag{8}$$

As this formula involves only cosines, a simple table lookup function, a microcomputer can be used to compute the value of τ.

With a 16-bit microcomputer, which permits 32-bit integers, equation (8) can be computed as written. However, with an 8-bit microcomputer such as used in the Lincoln ATARS system, several intermediate results can easily exceed the 16-bit integer limit. To see this, the equation must be rewritten according to the least significant bit values of each quantity:

$$\tau = \frac{[(\rho/5)^2 - (m/5)^2]}{(\rho/5) * \{(s/360) * (\cos\beta)/128 - (v/360) * [\cos(\beta-h)]/128\}}$$

$$\tau = \frac{128 * 360 * (\rho^2 - m^2)}{5*\rho*[s \cos\beta - v \cos(\beta - h)]} \tag{9}$$

where ρ, m, s, and v are now in uplink values

The constants arise as follows:

1. since a microcomputer is an integer machine, the fractional cosine values must be scaled 0 to 128
2. converting speeds in 10 knot lsb uplink units to speeds in miles/second involves a division by 360
3. the range and miss distance are each scaled in 0.2 mile lsb units in the uplink message, necessitating a division by 5 to get miles

In an 8-bit machine, the best order of computation steps is thus:

$$D = s \cos\beta - v \cos(\beta-h)$$

$$F = \left[\frac{128 * 360 + D/2}{D}\right]$$

$$\tau = F*\rho/5 - [F*m^2/5]/\rho \tag{10}$$

where the D/2 term provides more accurate roundoff.

Formula (10) is not as accurate as formula (8) because of integer division roundoff errors, particularly in the calculation of F. However, the percentage error in the computed τ is reasonably small, reaching a maximum of only 10% for a 700 knot closing encounter.

Sensitivity of τ to Data Truncation

Although equation (8) is far superior to equation (6) with respect to sensitivity to uplink data truncation, it will still be affected to some degree by this phenomenom. To determine how serious the error can be, a computer program was developed to test several representative threat scenarios: a near head-on collision, a 90° closing situation, and a shallow closing angle situation.

For each closing geometry, both slow (120 knot) and fast (360 knot) aircraft were considered for the own and threat aircraft, yielding four different cases. The results indicated that only when both aircraft were slow did any significant computation error occur for τ. This result is reasonable, as the quantities ρ, v, and s are smallest for this case, and thus most subject to large percentage truncation errors.

Figures A3, A4, and A5 present sequences of onboard τ values that would be computed for sample slow aircraft threat encounters. In each figure, two sequences are provided: the first for 128 knot aircraft and a miss distance of 0.35 miles, the second for 122 knot aircraft and a miss distance of 0.45 miles. Thus both large and small truncation cases for these quantities are shown.

These figures demonstrate that large errors in τ and a non-monotonic countdown with time are major issues only with the shallow encounter. This is again reasonable because of the smaller values of ρ for this geometry, leading to greater percentage truncation effects.

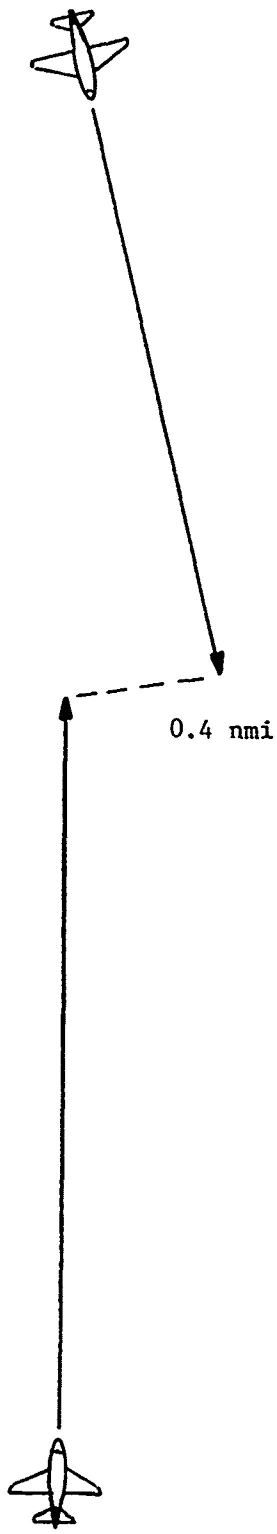
Although the sequences of τ in Fig. A5 have several anomalies, such as large jumps and occasional increases, the displayed values are in no case wildly different from the actual ones. Thus, it appears that an onboard computation of the time to closest approach is feasible.

Sensitivity of τ to Tracker Errors

The previous sections have concluded that the airborne values of times to closest approach will be approximately as good as those computed on the ground. However, this fact would be irrelevant if the latter values had large inaccuracies due to errors in the sensor tracker. In that event, the entire concept of a relative motion display would be questionable. This section will briefly attempt to investigate the expectable errors in τ for realistic trackers.

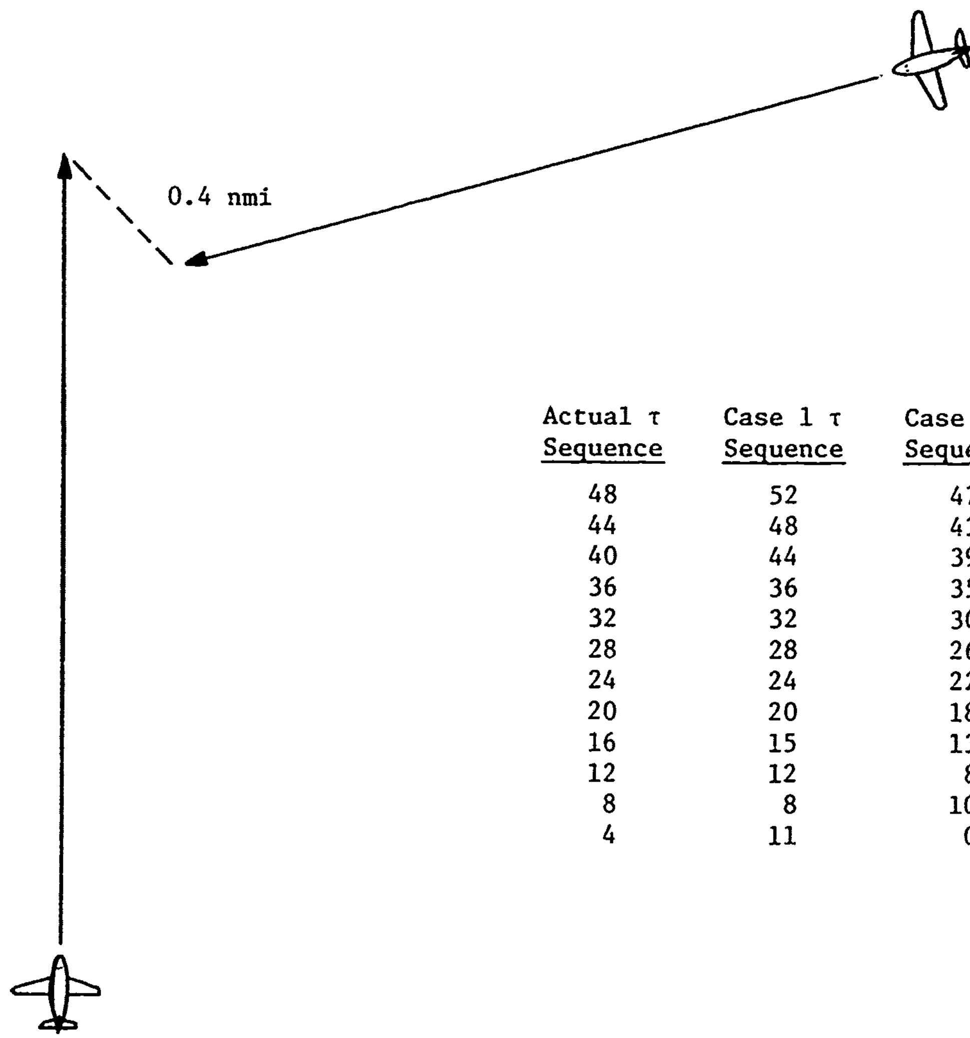
The first issue to consider is, assuming the tracker has accurate data on both of the aircraft (speeds, headings, locations), what affect will scan to scan tracker noise have on the sequence of values of τ it computes. If this noise is magnified, and large jumps or reversals in τ are expected, the time data would only confuse the pilot.

A computer program analyzed this question by introducing Gaussian noise into the tracker measurements on each scan for the trajectories shown in Figs. A3, A4, and A5. The assumed data variances were 1° for each heading, 2% for each velocity, and 60' for the range. It assumed further that the errors were independent from scan to scan, which tended to exaggerate the errors produced in τ. Even so, the results were that, in all cases, no error greater than 2 seconds occurred for τ. Thus, in particular, the values of τ always decreased from scan to scan. These results indicate that tracker noise is not a problem.



Actual τ Sequence	Case 1 τ Sequence	Case 2 τ Sequence
48	51	48
44	45	45
40	42	39
36	36	35
32	33	32
28	30	27
24	24	24
20	22	21
16	16	14
12	12	10
8	9	7
4	7	0

Fig. A3. Near Head-on Collision.



Actual τ Sequence	Case 1 τ Sequence	Case 2 τ Sequence
48	52	47
44	48	43
40	44	39
36	36	35
32	32	30
28	28	26
24	24	22
20	20	18
16	15	13
12	12	8
8	8	10
4	11	0

Fig. A4. 90° Closing Geometry.

Actual τ Sequence	Case 1 τ Sequence	Case 2 τ Sequence
48	47	45
44	48	45
40	40	37
36	41	37
32	31	27
28	32	27
24	24	16
20	24	17
16	15	19
12	17	0
8	21	0
4	0	0

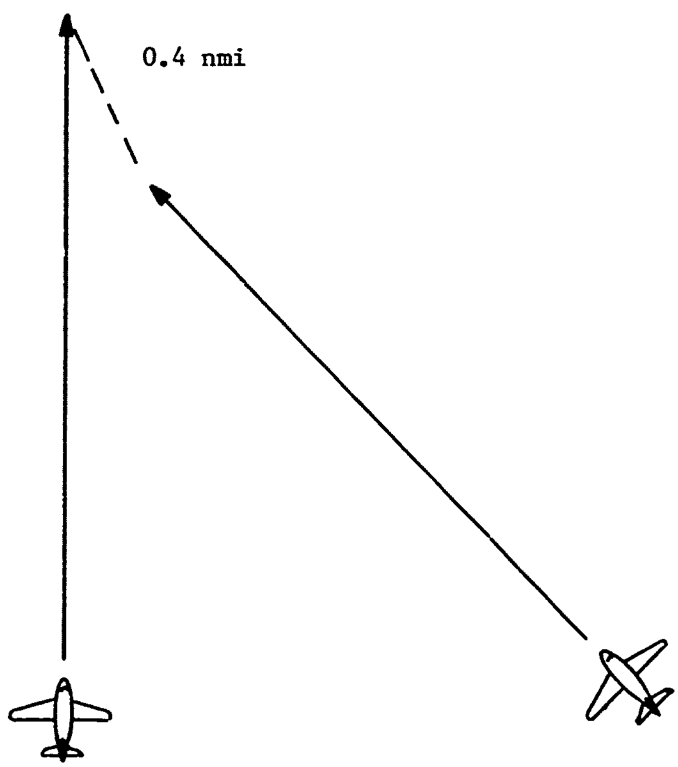


Fig. A5. Shallow Closing Geometry.

The second issue to consider is the effect that tracker biases will have on the closest approach data, either miss distance or τ. If an aircraft has been turning, or if its track is new to the sensor, bias errors as large as the following are possible:

heading: 15°
    thus, relative heading: 30°
        and bearing: 15°
velocity: 15%
range: 0.2 miles

Furthermore, since velocity information is transmitted on the uplink only at the start of a threat, the onboard computation could be using velocities as much as 25% in error.

A computer program calculated the values of miss distance and τ for each trajectory with these assumed errors. Not surprisingly, the values showed large errors were possible for both in all cases. The errors were particularly bad when slow speed aircraft were in conflict, and for all aircraft cases in the shallow encounter.

The potential for such large errors has been recognized by MITRE in their ATARS ground algorithms. In particular, they allow for the existence of heading errors by computing the worst case τ under the assumption that the aircraft may be turning. Also, a range guard is used to aid in detecting shallow angle threats.

Normally, tracker errors will be far smaller than those postulated above. Thus, the relative motion display and sequence of values of τ should be a usable pilot aid. However, only extensive flight testing could prove this point.

Conclusions

This appendix has demonstrated that the location of the closest point of approach and the expected time τ until it is reached can be computed by a microcomputer in the onboard ATARS display system on the second and subsequent scans of a threat encounter. Thus, a relative motion display is possible with the current uplink message formats.

The formula for τ is affected to some degree by uplink data truncation, but the results are well within the usable area. Also, an 8-bit microcomputer can perform the necessary computation.

Finally, ground tracker errors can strongly affect the values of miss distance and τ. Only a flight test program can answer whether these effects seriously hamper the usefulness of relative motion information.

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ACKNOWLEDGMENTS

The author is pleased to acknowledge the contributions of A. Kaminsky, G. Farmer, and J. Anderson in developing, building, and programming the AID display.